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DUAL-CHAMBER CONTROLLABLE SOLID PROPELLANT ROCKET MOTOR

THIRD ANNUAL REPORT - FISCAL YEAR 1964
Volume II - Analytical Study

November 1965

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AIR FORCE SYSTEMS COMMAND
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Prepared under Contract AF 04(611)-9067

by

Northrop Carolina, Inc., Asheville, North Carolina
A Subsidiary of Northrop Corporation

November 1965

APPROVED BY:

B. L. Johnson
Program Manager

[redacted]

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FOREWORD

This annual report for the continued development of a dual-chamber controllable solid propellant rocket motor (DCCSR) describes the progress during the third year of this program, which is sponsored by the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California. The research and development efforts of the program are being performed by Northrop Carolina, Inc., a Subsidiary of Northrop Corporation, Asheville, North Carolina, under Air Force Contract AF 04(611)-9067. This report is presented in two volumes: Volume I - Research and Development Efforts, and Volume II - Analytical Study. This volume (Volume II) presents the results of a study to determine the effect of motor performance parameters and propellant characteristics on the mass fraction, burnout velocity, and motor envelope of the dual-chamber controllable solid propellant rocket motor.

NOTICE

Northrop Carolina, Inc., has been assigned a patent application by the U. S. Patent Office to cover the Controllable Solid Propellant Rocket Motor invention disclosed in this publication, and the Commissioner of Patents has issued a secrecy order thereon. This secrecy order requires that those who receive a disclosure of the subject matter be informed of the existence of the secrecy order and of the penalties for the violation thereof.

The recipient of this report is accordingly advised that this publication includes information which is now under a secrecy order. It is requested that he notify all persons who will have access to this material of the secrecy order.

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It must be understood that the requirements of the secrecy order of the Commissioner of Patents are in addition to the usual security regulations which are in force with respect to classified materials in this report. The usual security regulations must still be observed notwithstanding anything set forth in the secrecy order. In the event that this report shall be declassified, the secrecy order remains in full force until it is specifically rescinded.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF TABLES

SECTION I - INTRODUCTION

1. GENERAL

Northrop Carolina, Inc., a subsidiary of Northrop Corporation, has been developing a dual-chamber controllable solid propellant rocket motor (DCCSR) under sponsorship of the Air Force Systems Command, Rocket Propulsion Laboratory, Edwards Air Force Base, California. This program, now in its third year, is funded under Contract AF 04(611)-9067. The progress of the program has been reported in quarterly and annual technical documentary reports (References 1 through 13). This volume presents the results of a separate parametric study conducted as part of the third year's effort.

The DCCSR concept is fully described and illustrated in Volume I. However, a brief description is given here to provide a better understanding of the information and data presented in this volume. The concept utilizes two propellant chambers separated by a throttle valve. The forward chamber contains a cool-burning fuel-rich propellant; the aft, an oxidizer-rich propellant. The fact that the forward-chamber combustion products are relatively cool burning (2800°F) permits state-of-the-art materials to be used on the aft chamber, where high-temperature combustion takes place. A multiple pyrogen ignition system is included as a part of the forward chamber. (Confidential)

Thrust is initiated by igniting the forward propellant with a single pyrogen. The relatively cool combustion products from the forward chamber are throttled through the control valve into the aft chamber where additional thermochemical reaction occurs, resulting in more energy release. The aft propellant will not burn without the heat supplied by the forward propellant. Throttleability is achieved by varying the forward-chamber pressure (and burning rate) by varying the position of the valve. The aft propellant actively supports combustion when the combustion gases from the forward propellant pass over it. (Confidential)

Thrust can be terminated at any time during the burning period by suddenly increasing the valve flow area, which produces a rarefaction wave that extinguishes combustion of the forward propellant. Since the aft propellant will not sustain combustion except at high chamber pressures and/or temperatures above 300°C without an external heat source, it too is extinguished. The on-off cycle operation can be repeated on command by reigniting the forward propellant using another pyrogen igniter of the multiple ignition system for each restart. (Confidential)

2. PURPOSE OF STUDY

This study was conducted in order to establish trends and optimum conditions of mass fraction, boost velocity, and motor envelope with variations in motor performance parameters and propellant characteristics for the dual-chamber controllable solid propellant rocket motor concept. It should be noted that the results presented herein do not necessarily represent optimum designs; rather, off-optimum as well as optimum conditions have been examined.

3. SCOPE

Five independent variables (motor performance parameters and propellant characteristics) were selected for this study: (1) total impulse, (2) minimum thrust, (3) thrust throttling range, (4) number of on-off cycles available, and (5) motor specific impulse. The first four variables define the capability of a throttleable stop-restart motor, and each directly affects mass fraction, boost velocity, and motor envelope. The fifth variable, which is a function of propellant composition, directly affects motor size and boost velocity.

The range of total impulse, minimum thrust, and thrust throttling range values included in this study are presented in Table I. Minimum thrust was varied from 1/500 to 1/20 of total impulse, that is, for maximum burn times of 20 to 500 sec. The thrust throttling ranges considered were 1 to 1, 5 to 1, and 20 to 1, and the number of on-off cycles used was 1, 10, 20, and 40. Vacuum specific impulse, at an expansion ratio of 20 to 1, was varied from 265 to 280 to 300 lb-sec/lb. It was felt that these ranges of independent variables would encompass those required in most applications of a DCCSR. (Confidential)

The analysis was divided into two phases. In Phase I, the independent variables listed above were investigated separately, with propellant properties and structural materials fixed. In Phase II, case

TABLE I - TOTAL IMPULSE AND THRUST RANGES FOR PARAMETRIC ANALYSIS

Total Impulse (lb_f-sec)	Minimum Thrust (lb_f)	Maximum Thrust (lb_f)		
		Case 1	Case 2	Case 3
10,000	20	20	100	400
10,000	50	50	250	1,000
10,000	100	100	500	2,000
10,000	500	500	2,500	10,000
100,000	200	200	1,000	4,000
100,000	500	500	2,500	10,000
100,000	1,000	1,000	5,000	20,000
100,000	5,000	5,000	25,000	100,000
500,000	1,000	1,000	5,000	20,000
500,000	2,000	2,000	10,000	40,000
500,000	5,000	5,000	25,000	100,000
500,000	25,000	25,000	125,000	500,000
1,000,000	2,000	2,000	10,000	40,000
1,000,000	4,000	4,000	20,000	80,000
1,000,000	10,000	10,000	50,000	200,000
1,000,000	50,000	50,000	250,000	1,000,000

(Confidential)

material, propellant mixture ratio, burning-rate constants, and burning-rate pressure exponents were varied as follows:

1. The effect of three case materials (steel, titanium and fiberglass) was evaluated for (1) the four thrust levels in the 100,000-lb-sec motor, (2) the other impulse levels at a minimum thrust corresponding to 200-sec operating time, and (3) for throttling ratios of 1, 5, and 20.

2. The effect of aft-to-forward-chamber propellant mixture ratios (2 to 1, 3 to 1, and 4 to 1) was investigated over the total impulse and minimum thrust range at a constant throttling ratio of 5 to 1.

3. The effect of burning-rate constants was investigated for the four thrust levels in the 100,000-lb-sec motor at a throttling ratio of 5 to 1.

4. The effect of propellant burning-rate (pressure) exponent was evaluated at throttling ratios of 1 to 1, 5 to 1, and 20 to 1 at a minimum thrust of 500 lb_f in the 100,000-lb-sec motor. The burning-rate exponents evaluated were: (1) for the forward chamber, 0.6, 0.8, and 0.9; (2) for the aft chamber, 0.8, 1.0, and 1.1. (Confidential)

The range of variables and constants used in this study are listed in detail in Section II, paragraph 1.

4. METHOD OF COMPUTATION

This study was carried out by means of Northrop Carolina's IBM 1620 Data Processing System and an IBM 1622 Card Read Punch, which assured accurate and rapid processing of the required data. The data processing system's limited storage capacity (20,000 digits) necessitated the processing of data through four separate computer subroutines. These subroutines, prepared by Northrop Carolina, consisted of (1) a steady-state internal ballistics subroutine, (2) a grain configuration subroutine, and (3) two weight subroutines. The information flow through these subroutines is shown in Figure 1. A detailed description of the subroutines and the overall computer program is presented in Section II.

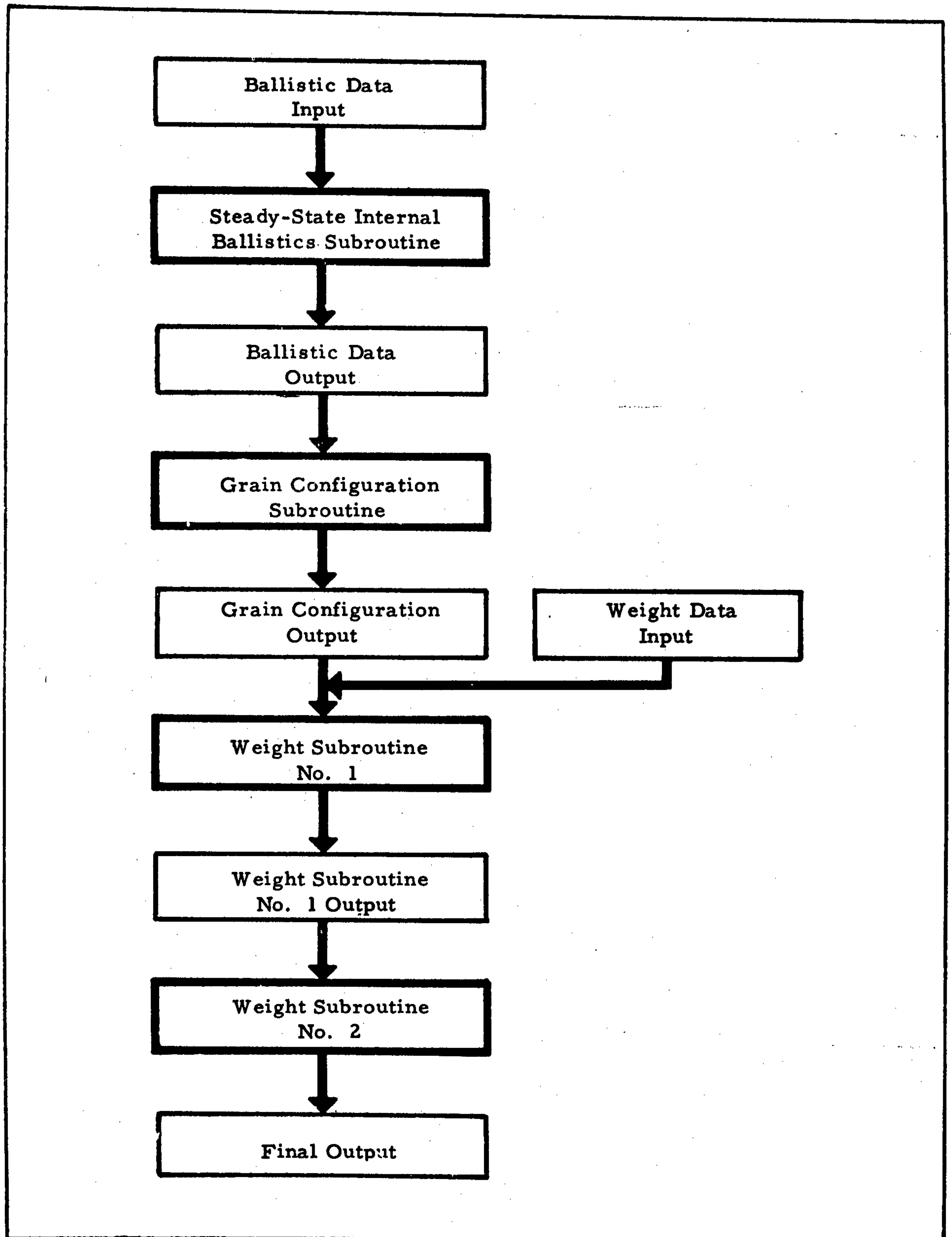

Figure 1 - Computer Program Diagram, Showing Information Flow through Subroutines

SECTION II - TECHNICAL APPROACH

1. PARAMETER SELECTION

a. General

As mentioned in Section I, this parametric study was conducted in two phases. The effect of the major ballistic parameters was investigated in Phase I; the remaining, less significant parameters in Phase II. As a result, more computer runs were required for Phase I than for Phase II.

Table II summarizes the parameters investigated in each phase, showing which were varied and which held constant. Note that, as shown in Table II, Phase II was subdivided into Phases IIa through IId, depending on the parameters that were held constant, as follows:

Phase	Variable
II a	Case material
II b	Burning rate
II c	Propellant burning rate exponent
II d	O/F ratio, θ (theta)

The values and ranges of the parameters investigated in each phase are listed in paragraphs b and c, below, respectively.

b. Phase I Parameters

The values of the constants used in Phase I are listed below.

Constant	Value
Case material	Steel
O/F ratio, θ	3.0
Forward propellant density ($lb_m/in.^3$)	0.053
Aft propellant density ($lb_m/in.^3$)	0.070

TABLE II - PARAMETERS INVESTIGATED IN EACH PHASE*

Parameter	Phase				
	I	II a	II b	II c	II d
Total impulse, vacuum (lb_f-sec)	V	V	C	C	V
Specific impulse, vacuum (lb_f-sec/lb_m)	V	C	C	C	C
Minimum thrust (lb_f)	V	V	V	C	V
Thrust ratio, maximum/minimum	V	V	C	V	C
Starts	V	C	C	C	C
Case material	C	V	C	C	C
Aft propellant rate constant (in./sec)	C	C	V	C	C
Forward propellant rate constant (in./sec)	C	C	V	C	C
Aft propellant burning-rate exponent	C	C	C	V	C
Forward propellant burning-rate exponent	C	C	C	V	C
O/F ratio, θ	C	C	C	C	V
Aft propellant density ($lb_m/in.^3$)	C	C	C	C	C
Forward propellant density ($lb_m/in.^3$)	C	C	C	C	C
Aft propellant flame temperature (^oF)	C	C	C	C	C
Forward propellant flame temperature (^oF)	C	C	C	C	C
Aft chamber C_d (sec^{-1})	C	C	C	C	C
Forward chamber C_d (sec^{-1})	C	C	C	C	C
Minimum aft chamber pressure (psia)	C	C	C	C	C
Minimum forward chamber pressure (psia)	C	C	C	C	C
Expansion ratio	C	C	C	C	C

*C and V denote constant and variable, respectively.

(Confidential)

Constant	Value
Forward propellant exponent, n	0.80
Aft propellant exponent, n	1.00
Forward propellant rate constant (in./sec)	0.0008
Aft propellant rate constant (in./sec)	0.0004
Forward propellant flame temperature (°F)	2700
Aft propellant flame temperature (°F)	5500
C_d, forward chamber (sec^{-1})	0.00765
C_d, aft chamber (sec^{-1})	0.00643
Minimum forward-chamber pressure (psia)	100.0
Minimum aft-chamber pressure (psia)	50.0
Expansion ratio	20.0

(Confidential)

The range of the variables used for Phase I are as follows:

Variable	Range
Total impulse (lb_f-sec)	10^4 to 10^6
Maximum/minimum thrust ratio	1, [illegible]
Minimum thrust (lb_f)	[illegible], 000
Specific impulse, vacuum (lb_f-sec/[illegible])	[illegible] 280, 300
Starts	1, 10, 20

(Confidential)

c. Phase II Parameters

The less significant parameters (case material, burn rate, pressure exponent, and theta) were varied in Phase II. The range of these variables and the values of the constants used in each portion of Phase II are listed below.

Phase II a

Constants - Same as Phase I, except for the following:

Case Material	Listed below
Specific impulse, vacuum (lb_f-sec/lb_m)	280
Starts	20

Variables

Maximum/minimum thrust ratio	1, 5, 20
Case material	Steel, Fiberglass, Titanium
Total impulse (lb_f-sec)	10^4 to 10^6
Minimum thrust (lb_f)	50 to 5000

Phase II b

Constants - Same as Phase I, except for the following:

Burn rate constants	Listed below
Specific impulse, vacuum (lb_f-sec/lb_m)	280
Starts	20
Maximum/minimum thrust ratio	5
Total impulse (lb_f-sec)	10^5

Variables

Aft propellant burn rate constant (in./sec)	0.0001 to 0.0010
Forward propellant burn rate constant (in./sec)	0.0002 to 0.0032
Minimum thrust	200 to 500

Phase II c

Constants - Same as Phase I, except for the following:

Burn rate exponents	Listed below
Specific impulse, vacuum (lb_f-sec/lb_m)	280
Starts	20

Total impulse (lb_f-sec)	10^5
Minimum thrust (lb_f)	500

Variables

Aft propellant exponent	0.8 to 1.1
Forward propellant exponent	0.6 to 0.9
Maximum/minimum thrust ratio	1, 5, 20

Phase II d

Constants - Same as Phase I, except for the following:

Theta	Listed below
Specific impulse, vacuum (lb_f-sec/lb_m)	280
Starts	20
Maximum/minimum thrust ratio	5

Variables

Theta	2.0 to 4.0
Total impulse (lb_f-sec)	10^4 to 10^6
Minimum thrust (lb_f)	50 to 5000

(Confidential)

d. Output Parameters

The parameters listed in c and d, above, were used as inputs to the computer program. The chief dependent variables calculated (computer outputs) were:

1. Mass fraction
2. Delta velocity, ideal (fps)
3. Total motor length (in.)
4. Total motor diameter (in.)
5. Grain design

For some computer runs, other values were calculated as data checks; however, they are not presented here.

2. INTERNAL BALLISTICS SUBROUTINE

The internal ballistics subroutine was prepared to calculate ballistic design and performance parameters for the DCCSR motor under steady-state operating conditions. This subroutine contains two principal options which permit the program to be used to design aft-chamber parameters and calculate performance for test motors (Option I) or to design motors to meet specified thrust and total impulse requirements (Option II). The general subroutine logic is shown in the diagram in Figure 2; the actual IBM 1620 computer subroutine listing is given in Appendix A.

The equations employed in this subroutine are conventional ballistic relationships which have been modified for dual-chamber motors, as outlined previously (Reference 1). The forward chamber, with choked flow at the valve, operates as a conventional rocket motor. Aft-chamber parameters are calculated as a function of the ratio of aft-to-forward mass flow, θ, which under steady-state conditions is defined as:

$$\theta = \frac{(\rho SaP^n)_{aft}}{(\rho SaP^n)_{fwd}}, \tag{1}$$

where

ρ = propellant density,

S = burning area,

a = burn-rate constant,

P = operating pressure, and

n = pressure exponent*

The aft-chamber surface area was calculated by rearranging this equation, as follows:

$$S_{aft} = \theta \frac{\left(\rho SaP^n_{min}\right)_{fwd}}{\left(\rho aP^n_{min}\right)_{aft}}. \tag{2}$$

---

*Also referred to as burning-rate exponent herein.

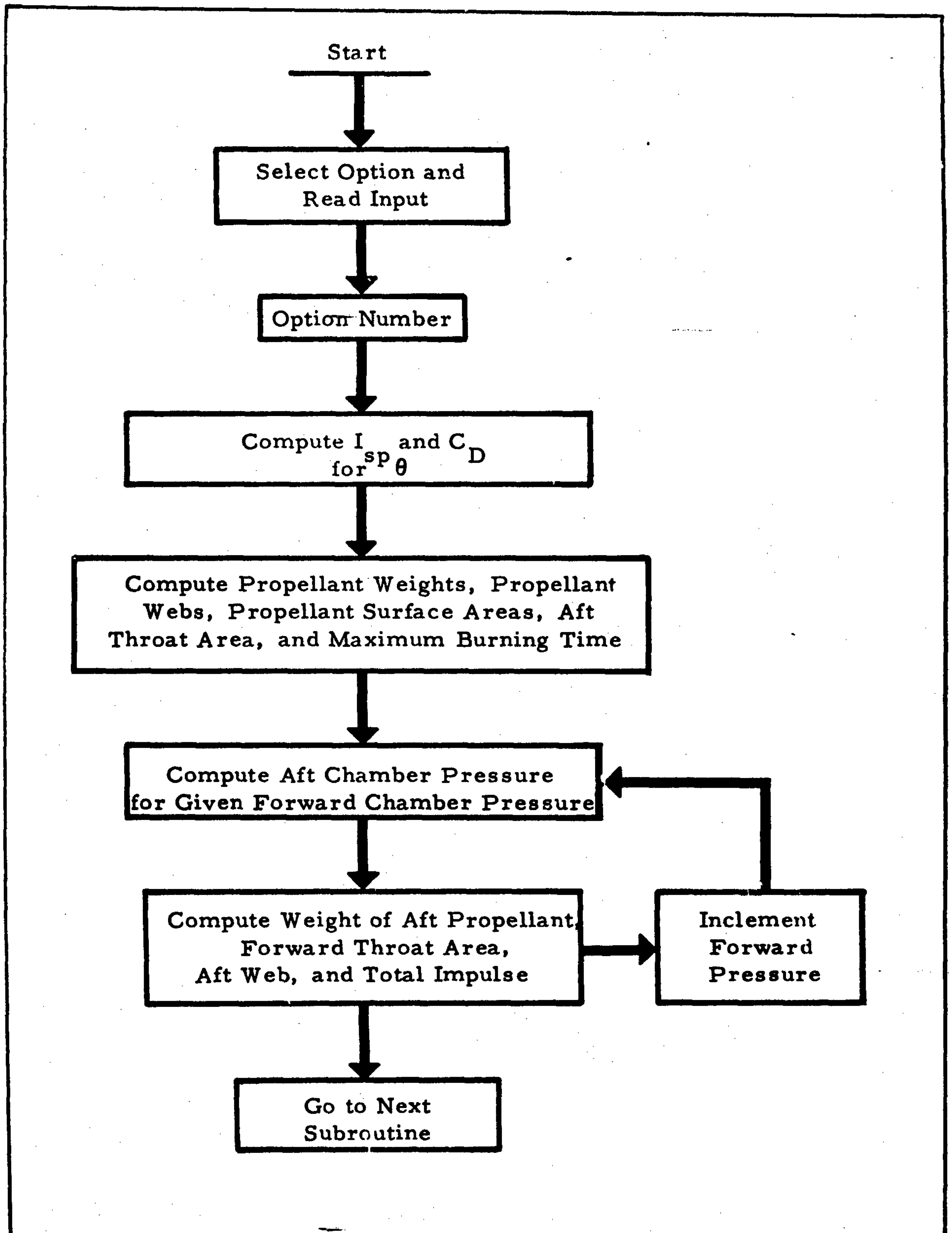

Figure 2 - Internal Ballistics Subroutine Logic Diagram

The over-all mass flow balance for the motor is

$$\dot{M}_{fwd} + \dot{M}_{aft} = \dot{M}_{tot} = (C_d\, P\, A_t)_{aft}\,, \tag{3}$$

where

C_d = discharge coefficient at aft nozzle, and

A_t = aft nozzle throat area.

Hence,

$$(\rho SaP^n)_{fwd} + (\rho SaP^n)_{aft} = (C_d\, P\, A_t)_{aft}\,, \tag{4}$$

or

$$1 + \theta = \frac{(C_d\, P\, A_t)_{aft}}{(\rho SaP^n)_{fwd}}. \tag{5}$$

The aft-chamber throat area was calculated by rearranging Equation 5; that is,

$$A_{t_{aft}} = (1 + \theta)\,\frac{(\rho SaP^n{}_{min})_{fwd}}{(C_d\, P_{min})_{aft}}\,. \tag{6}$$

Aft-chamber pressure was calculated as a function of forward-chamber pressure from Equation 4 by an iterative procedure. Initially, an estimate of aft-chamber pressure was substituted into the left side of Equation 4, and the aft-chamber pressure on the right side was calculated from

$$P_{aft} = \frac{(\rho SaP^n)_{fwd} + (\rho SaP^n{}_{est})_{aft}}{(C_d\, A_t)_{aft}}\,.$$

The calculated pressure was then compared with the estimated pressure. If the two did not agree within 0.5 percent, another estimated pressure was obtained by

$$P_{est_n} = 2\,P_{calc_{(n-1)}} - P_{est_{(n-1)}}\,,$$

and the procedure repeated until convergence was achieved.

When the calculated pressure agreed with the estimated pressure within 0.5 percent, θ was calculated from Equation 1 and compared with the estimated θ from which $C_{d_{aft}}$ was obtained. If these did not agree within 0.5 percent, a new θ was estimated and aft-chamber pressure was calculated using a new $C_{d_{aft}}$. This procedure was repeated until convergence was achieved. Thrust was then calculated from the product of specific impulse at the final θ value and mass flow rate.

3. GRAIN CONFIGURATION SUBROUTINE

The grain configuration subroutine was prepared for determining the most suitable grain configurations for the DCCSR forward and aft chambers. The subroutine calculated the diameter, length, port area, and volumetric loading of the grains, but did not calculate the detailed grain design. The four basic grain types employed, in order of increasing mass flow requirements, were end burning, cylindrically (center) perforated, star, and wagon-wheel designs. These configurations were selected for either a cylindrical or spherical forward chamber and for a cylindrical aft chamber, either in tandem or around the outside of the forward chamber. The required input for this subroutine, supplied by the steady-state internal ballistics subroutine, consisted of forward- and aft-grain burning surface areas and web thicknesses, , and aft-chamber throat area. The subroutine output provided the dimensions necessary for case and insulation design. The subroutine logic is shown in the diagram in Figure 3, while the actual computer subroutine listing is given in Appendix A.

The equations employed in this subroutine are general geometry equations that relate diameters to areas and volumes of both cylinders and spheres; the actual equations used are shown in the program listing for this subroutine in Appendix A. The subroutine initially established the forward-grain configuration and its dimensions, based on forward-grain surface area and web thickness inputs. First, a cylindrical end-burner design was assumed and the grain diameter calculated from the inputs. If the length-to-diameter ratio of this design was less than 0.5, the cylindrical end-burner design was rejected and a spherical end burner assumed. The program thus proceeded from designs with high web fractions to those with low web fractions until a design with a reasonable length-to-diameter ratio was obtained. The program then printed out the type of configuration, grain outside diameter, length, and volumetric loading. For cylindrical

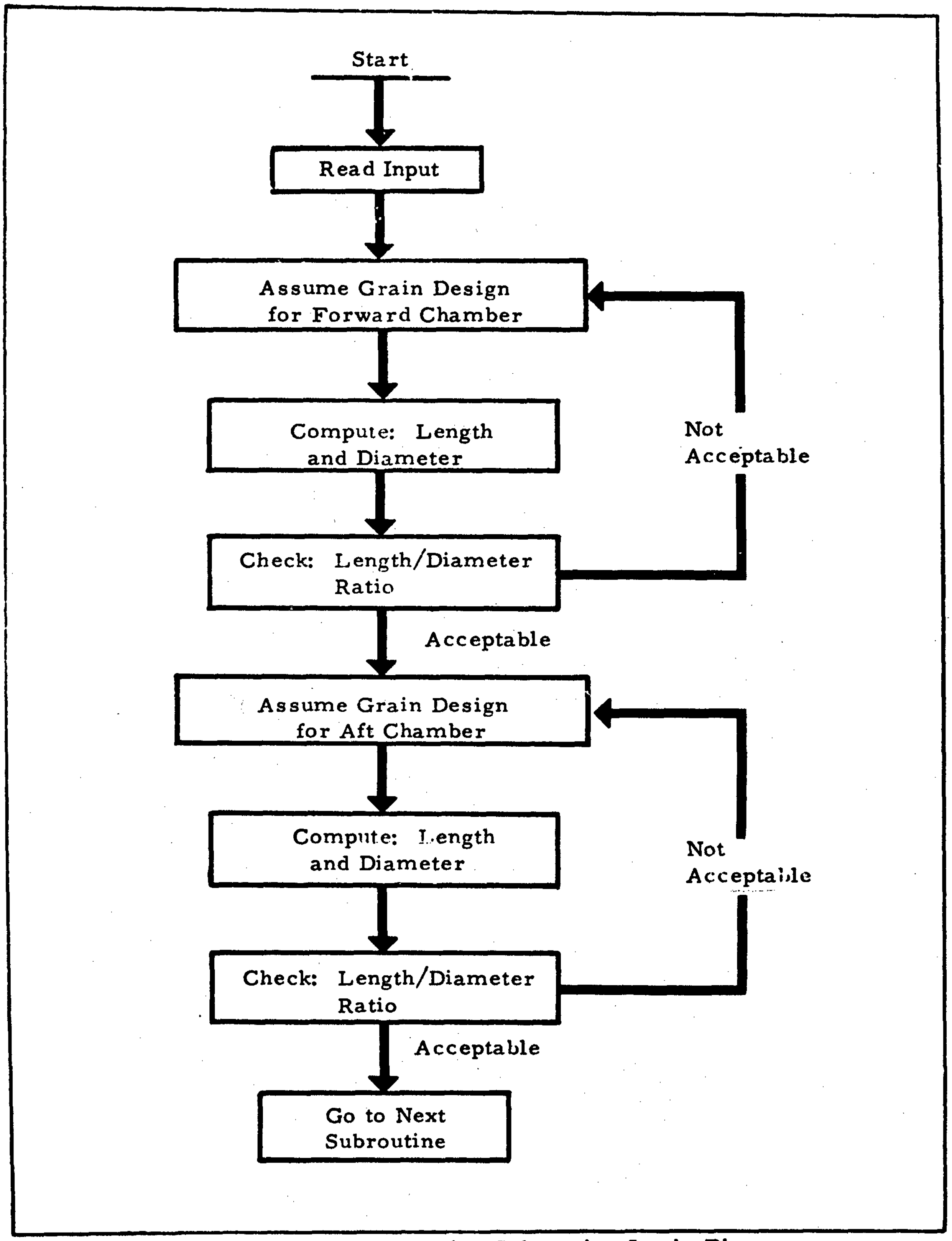

Figure 3 - Grain Configuration Subroutine Logic Diagram

center perforated and star designs, the program would, when feasible, give an alternate spherical forward-chamber design.

After the forward grain configuration was selected, the subroutine had the option of proceeding to another case or establishing the aft-grain configuration. The aft-grain program was similar to the forward one in that designs with increasing web-to-diameter ratios were considered until a design giving a reasonable length-to- diameter ratio was achieved. An attempt was made to design an aft grain with an outside diameter equal to that of the forward. If this diameter proved to be unsatisfactory, larger or smaller diameters were used. For forward-chamber designs with high length-to-diameter ratios, the aft-chamber subroutine considered the feasibility of placing the aft chamber around the forward chamber, rather than in tandem, to reduce the over-all length-to-diameter ratio for the dual-chamber system. Figure 4 shows some typical configurations for chambers in tandem and with one chamber inside the other.

The subroutine assumed that the surface-time history of the selected grain configuration was neutral. This assumption is true for end-burning grains and can be made approximately so for the star and wagon-wheel configurations. Although most of the cylindrically perforated designs would not be neutral, this can be corrected in a detailed design by using slotted-tube configurations of approximately the same diameter and length.

4. WEIGHT SUBROUTINES

a. General

As mentioned in Section I, the weight calculation subroutine was divided into two parts (A and B) to facilitate computation in Northrop-Carolina's IBM 1620 computer. The subroutine calculated the weight and dimensions of the forward and aft motor case, end closures, insulation, nozzle, igniters, and the control valve. The weights and dimensions were selectively calculated, depending on geometrical constraints such as the forward- and aft-chamber grain configurations and the materials used for each individual component. The generalized flow diagrams for the two weight subroutines are shown in Figures 5 and 6, respectively. The subroutine program listings are given in Appendix A.

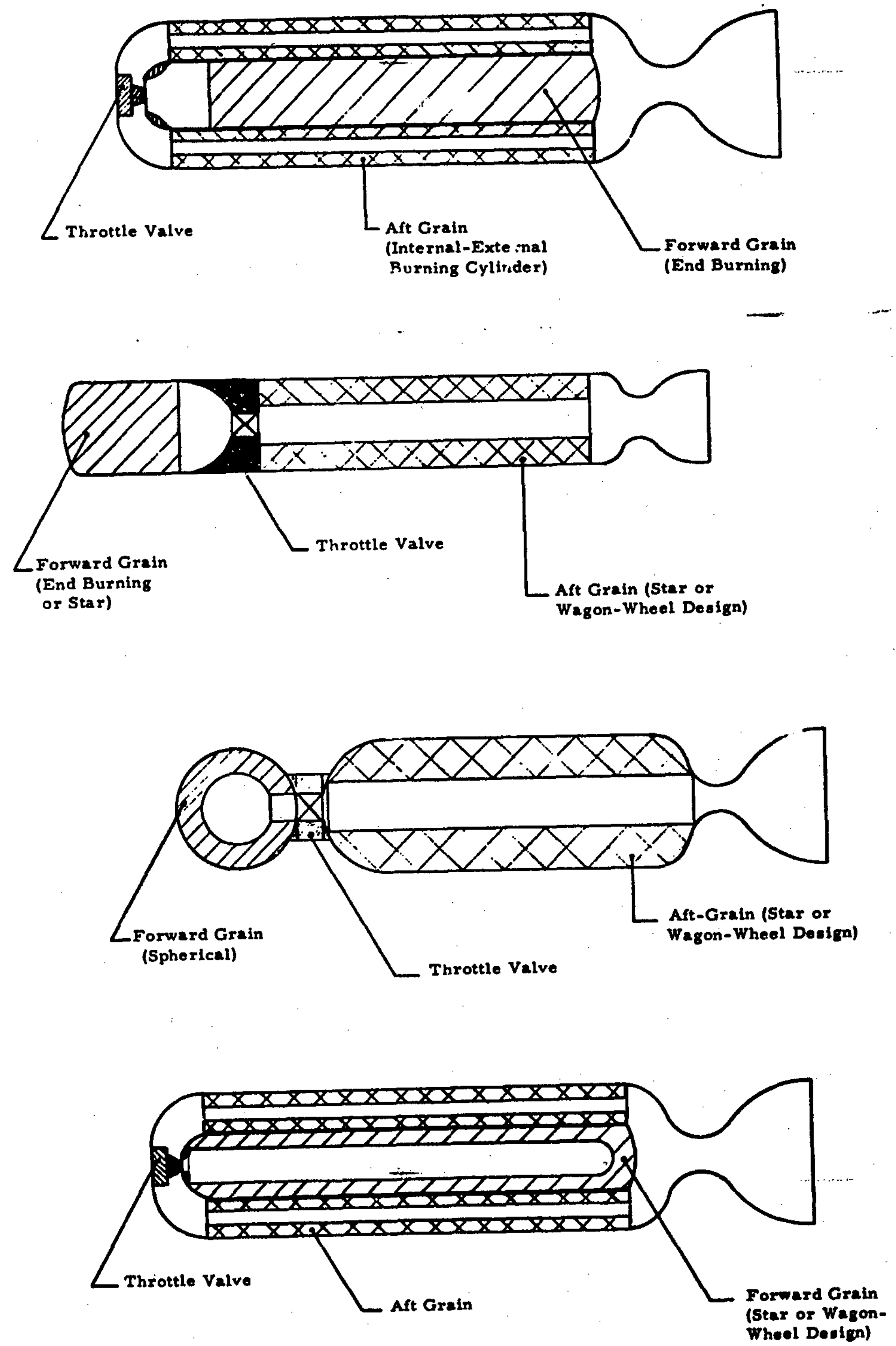

Figure 4 - Typical Configurations Considered in Grain Configuration Subroutine

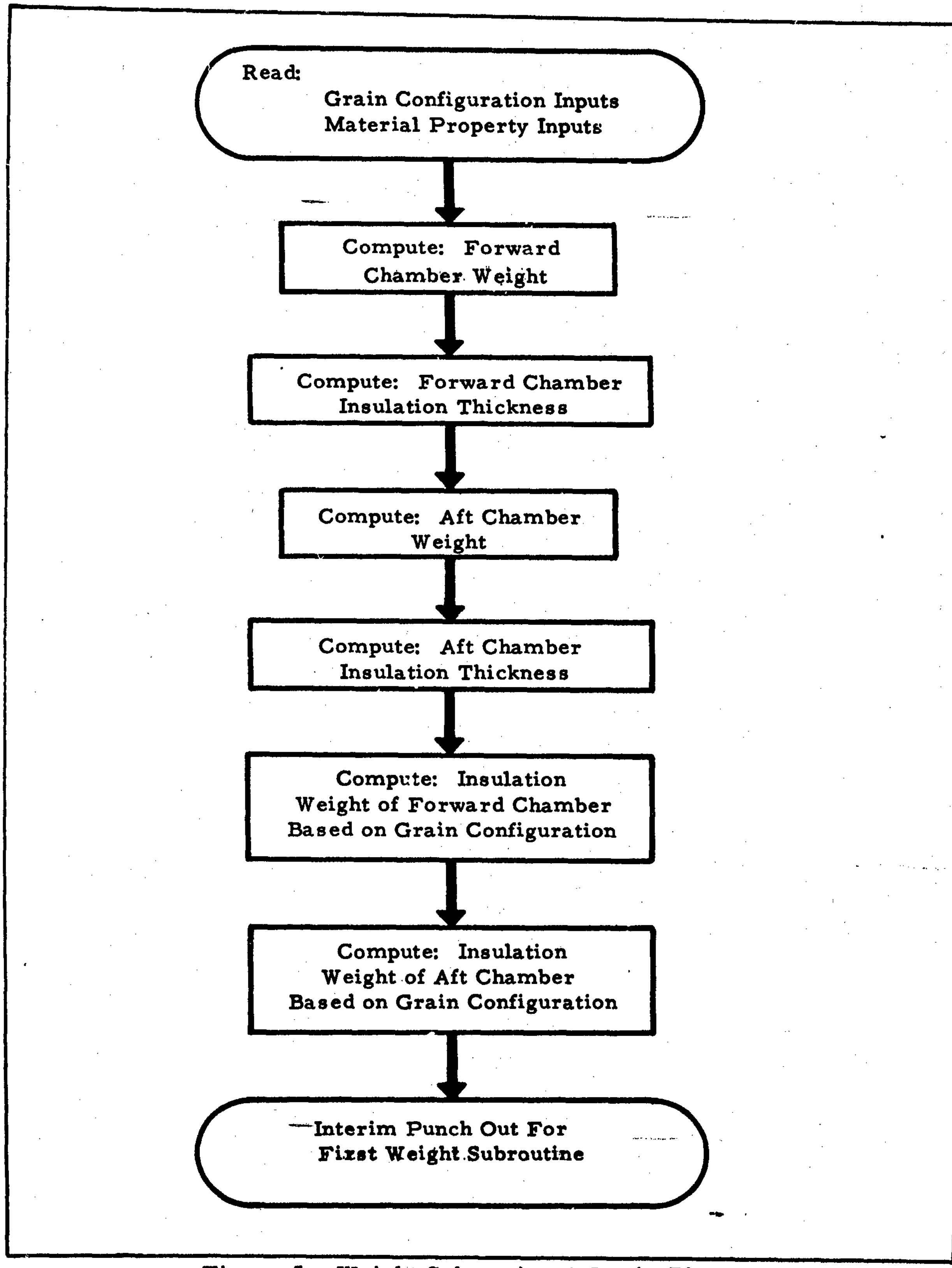

Figure 5 - Weight Subroutine A Logic Diagram

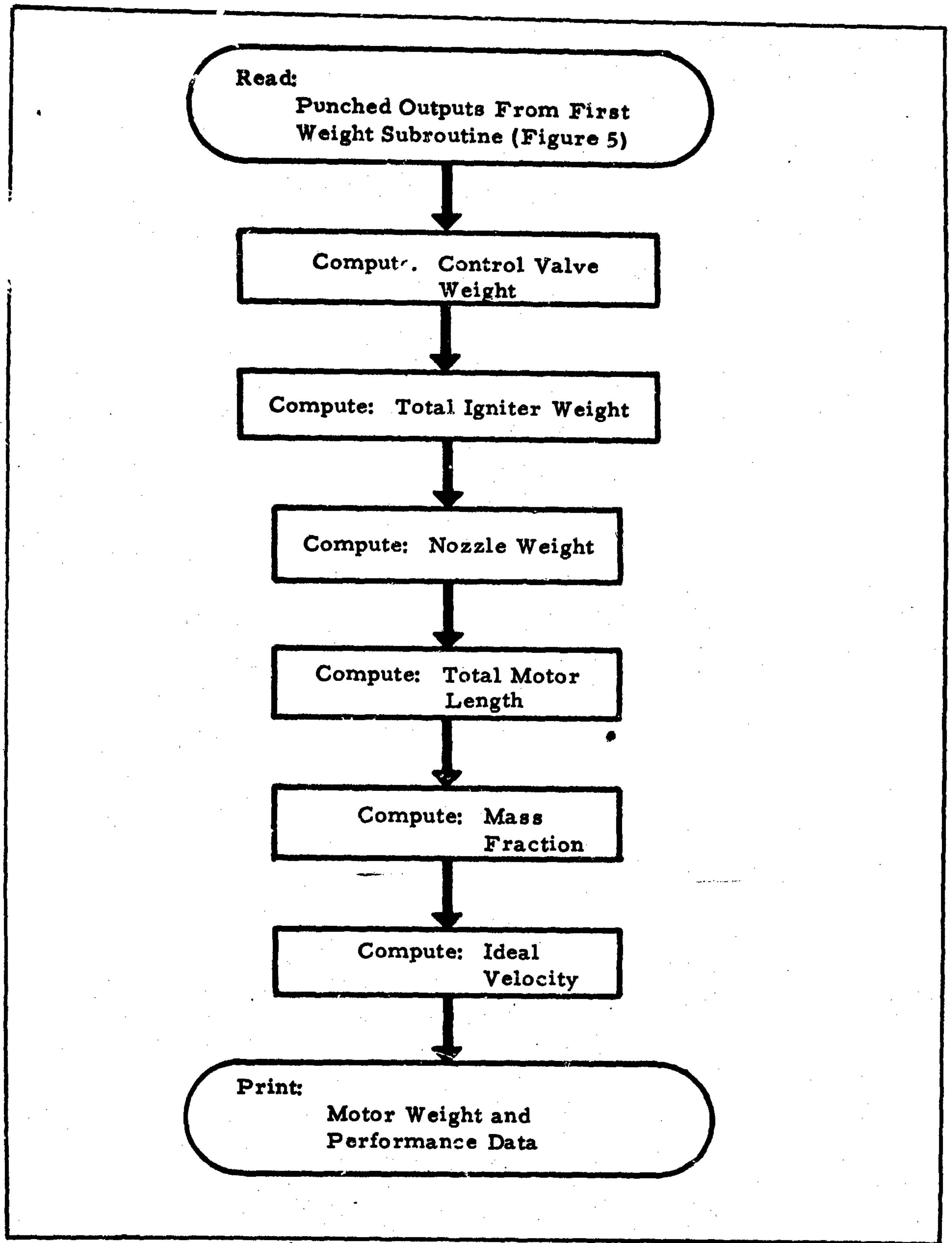

Figure 6 - Weight Subroutine B Logic Diagram

b. <u>Chamber Weights</u>

Chamber weights were calculated by multiplying the chamber surface area by the thickness of the particular section (based on the operating pressure times material density. The weight of the head closures was calculated from

$$W_{ellipsoid} = t_{ell}\, \rho \pi \, [R^2 + (\frac{b^2}{2e})(\ln \frac{1+e}{1-e})\,], \qquad (7)$$

where

$$t_{ell} = \frac{PRSF}{\sqrt{2}\sigma}, \text{ and}$$

$$e = \frac{\sqrt{R^2 - b^2}}{R^2}.$$

The cylindical chamber weight was calculated from

$$W_{cyl} = t_{cyl}\, \rho 2\pi R, \qquad (8)$$

where

$$t_{cyl} = \frac{PRSF}{\sigma}.$$

The symbols used in Equations 7 and 8 are defined below:

$W_{ellipsoid}$	=	total head closure weight (lb_m)
W_{cyl}	=	total cylindrical chamber weight (lb_m)
t_{ell}	=	thickness of head closure (in.)
t_{cyl}	=	thickness of cylindrical chamber (in.)
ρ	=	material density (lb_m/in.^{3})
R	=	major case radius (in.)
b	=	minor ellipse radius (in.)
e	=	ellipse eccentricity ratio
σ	=	material yield strength (lb_f/in.^{2})
SF	=	safety factor
P	=	operating pressure (psia)

c. Valve and Power Supply Weights

Valve and power supply weights were determined by a parametric derivation of each component's contribution to total control weight as a function of valve size. The weight equations used for each component are listed below:

Component	Weight Equation	
Intermediate plate	$W = 0.00939\, D_t^3\, (\Delta P)^{\frac{1}{2}}$	
Intermediate plate insulation	$W = 0.0025\, D_t^2\, t_b$	$(t_b \geq 9$ sec)
	$W = 0.0225\, D_t^2$	$(t_b < 9$ sec)
Housing insulation	$W = 0.00233\, D_t^2\, t_b$	$(t_b \geq 9$ sec)
	$W = 0.02097\, D_t^2$	$(t_b < 9$ sec)
Tube insulation	$W = 0.0053\, D_t^2\, t_b$	$(t_b \geq 9$ sec)
	$W = 0.0476\, D_t^2$	$(t_b < 9$ sec)
Piston insulation	$W = 0.00162\, D_t^2\, t_b$	$(t_b \geq 9$ sec)
	$W = 0.0146\, D_t^2$	$(t_b < 9$ sec)
Pintle	$W = 0.0282\, D_t^3$	$(D_t \geq 1.07$ and $L = f(D_t))$
	$W = 0.0302\, D_t^2$	$(D_t < 1.07)$
Power pack	$W = 0.33\, D_t^3$	
Servovalves	$W = 0.59\, D_t^3 + 0.9$	
Piston	$W = 0.022\, D_t^2 + 0.00676\, D_t^3$	$(D_t \geq 2.67)$
	$W = 0.0403\, D_t^2$	$(D_t < 2.67)$

Component	Weight Equation
End of piston	$W = 0.022\, D_t^2 + 0.0000581\, D_t^3 \sqrt{P}$ $(D_t \geq 0.68)$
	$W = 0.22\, D_t^2 + 0.0000294\, D_t^2 \sqrt{P}$ $(D_t < 0.68)$
Cylinder	$W = 0.0297\, D_t^3$ $(D_t \geq 2.9)$
	$W = 0.00792\, D_t^2 + 0.027\, D_t^3$ $(D_t < 2.9)$
Duct	$W = CD_t^3 = 0.00563\, D_t^3$ $(D_t \geq 10.7)$
	$W = CD_t^2 = 0.0602\, D_t^2$ $(D_t < 10.7)$
Struts	$W = 0.000301\, D_t^3 P^{\frac{2}{3}}$
Housing	$W = 0.0966\, D_t^3$ $(D_t \geq 2.38)$
	$W = 0.0934\, D_t^2 + 0.575\, D_t^3$ $(D_t < 2.38)$

where

$D_t = \sqrt{\dfrac{4 V_f}{\pi C}}$ (input),

t_b = burn time,

ΔP = forward-chamber pressure - aft-chamber pressure (maximum),

C = constant input, and

V_f = final free volume of forward chamber.

d. Insulation Weights

Insulation weight was determined as a function of exposed insulation area, flame temperature, burning time, and insulation density, by means of the following equation:

$$W_{ins} = A_{ins}\, \rho\, t_{ins},$$

where

$$t_{ins} = 0.007\, t_b \left(\frac{T_c + 460}{5806}\right)^4 + 0.05,$$

A_{ins} = exposed insulation surface area (in.^{2})

ρ = insulation density (lb_m/in.^{3})

t_b = maximum duration (sec), and

T_c = chamber flame temperature ($^\circ$F).

e. Nozzle Weights

Nozzle weight was determined by the following empirically derived equation, which is dependent upon the yield strength of the material used in each component of the nozzle, flame temperature, expansion ratio, throat area, chamber pressure, maximum burn time, and propellant C^*:

$$W_{noz} = \frac{(104 + 9.65^{\epsilon})(A_t)^{1.5}}{10^6} P_{c_{max}} + 1.53\,(A_t)^{0.9}$$
$$+ \left[\frac{0.00268\, t_b \left(\frac{C^*}{32.2}\right)^{1.7} (P_{c_{max}})^{0.8} + 0.1}{10^6}\right] \times$$
$$(0.0865)\,(\epsilon - 4)\, A_t,$$

where

ϵ = expansion ratio,

A_t = throat area (in.^{2})

$P_{c_{max}}$ = maximum chamber pressure ($lb_f/in.^2$)

t_b = maximum burn time (sec), and

C^* = propellant characteristic velocity (fps).

f. Subroutine Output Data

Output data from these subroutines was very complete. An attempt was made to summarize all motor characteristics, dimensions, and weights in one tabulation, shown in Table III. Output data are coded by a line heading that increases from 100 to 1800.

TABLE III - OUTPUT FORMAT OF WEIGHT SUBROUTINE

100	Strength/Density, Nozzle Structure	Strength/Density, Nozzle Throat	Strength/Density, Nozzle Exit	Strength/Density, Aft Chamber	Strength/Density, Forward Chamber	Total Impulse
200	Flame Temperature, Aft Chamber	Flame Temperature, Forward Chamber	Maximum Aft-Chamber Pressure	Maximum Forward-Chamber Pressure	Minimum Aft-Chamber Pressure	
300	L/D Aft Chamber	L/D Forward Chamber	Ellipse Ratio, Aft Chamber	Ellipse Ratio, Forward Chamber	Diameter, Aft Chamber	Diameter, Forward Chamber
400	Number of Chambers		Propellant Weight, Aft Chamber	Propellant Weight, Forward Chamber	Maximum Burn Time	
500	Throat Area, Aft Chamber	Throat Area, Forward Chamber	Maximum Propellant Surface Area, Aft Grain	Maximum Propellant Surface Area, Forward Grain	Insulation Density, Aft Chamber	Insulation Density, Forward Chamber
600	Flame Temperature of Igniter	Gas Molecular Weight, Aft Chamber	Gas Molecular Weight, Forward Chamber	Propellant Burn Rate Constant, Aft Chamber	Propellant Burn Rate Constant, Forward Chamber	
700	Igniter Safety Factor	Gas Molecular Weight, Igniter	Number of Igniters	Percent of Gas in Ignition Exhaust	Ignition Constant	Igniter Mass Fraction
800	n, Aft Propellant	n, Forward Propellant			Thermal Conductivity, Aft Propellant	Thermal Conductivity, Forward Propellant
900	Total Igniter Weight	Igniter Propellant Weight	Individual Igniter Weight	Propellant Density, Aft Chamber	Propellant Density, Forward Chamber	Discharge Coefficient, Aft Chamber
1000	Total Insulation Weight	Insulation Weight of Forward Closure, Aft Chamber	Insulation Weight of Aft Closure, Aft Chamber	Insulation Weight of Cylinder, Aft Chamber	Total Insulation Weight, Aft Chamber	Motor Configuration, Forward Grain
1100	Insulation Weight of Forward Chamber	Insulation Weight of Aft Closure, Forward Chamber	Insulation Weight of Cylinder, Forward Chamber	Total Insulation Weight, Forward Chamber		
1200	Weight of Forward Closure, Aft Chamber	Weight of Aft Closure, Aft Chamber	Weight of Cylinder, Aft Chamber	Weight of Aft Chamber	Motor Configuration, Aft Grain	
1300	Weight of Forward Closure, Forward Chamber	Weight of Aft Closure, Forward Chamber	Weight of Cylinder, Forward Chamber	Weight of Aft Chamber		
1400	Thickness of Cylinder, Aft Chamber	Thickness of Insulation, Aft Chamber	Thickness of Cylinder, Forward Chamber	Thickness of Insulation, Forward Chamber	Density of Aft Chamber Material	Density of Forward Chamber Material
1500	Total Valve Weight	Valve Insulation Weight	Piston End Weight	Piston Pintle Housing Weight		
1600	Servo Weight, Power Pack Intermediate Plate	Power Pack Weight	Intermediate Plate Weight	Strut Weight	Duct Weight	Cylinder Weight
1700	Nozzle Weight	Nozzle Structure Weight	Nozzle Throat Weight	Nozzle Insulation Weight	Expansion Ratio	
1800	Total Motor Weight	Maximum Motor Diameter	Maximum Motor Length	Mass Fraction	Ideal Velocity	Motor L/D

SECTION III - DISCUSSION OF RESULTS

1. GENERAL

The over-all results of the parametric study are presented and discussed in this section. The data from the computer runs have been plotted in semi-logarithmic form to facilitate analysis. The data from these basic plots, which are presented sequentially in Appendix B by phase and variable, have been cross-plotted and presented in this section to highlight the trends observed.

This section is organized by study phase, with the effect of each independent variable discussed separately.

2. PHASE I

a. General

In Phase I, the effect of specific impulse, thrust ratio, number of starts, total impulse, and minimum thrust on mass fraction and delta velocity was studied. The effect of each of these variables is discussed below.

b. Specific Impulse

The effects of specific impulse on mass fraction and delta velocity, for a thrust ratio of 1 and 10 starts, are shown in Figures 7 and 8, respectively. As shown in Figure 7, mass fraction decreases slightly with increasing specific impulse. However, delta velocity increases as specific impulse is increased. Curves for higher thrust ratios and other than 10 starts are similar, but the mass fraction and delta velocity levels differ. (Confidential)

c. Thrust Ratio

In Figures 9 and 10, the effects of thrust ratio (that is, maximum thrust/minimum thrust) on mass fraction and delta velocity are shown, for 10 starts and a specific impulse of 280 lb_f-sec/lb_m. For thrust ratios up to 5, the penalty on

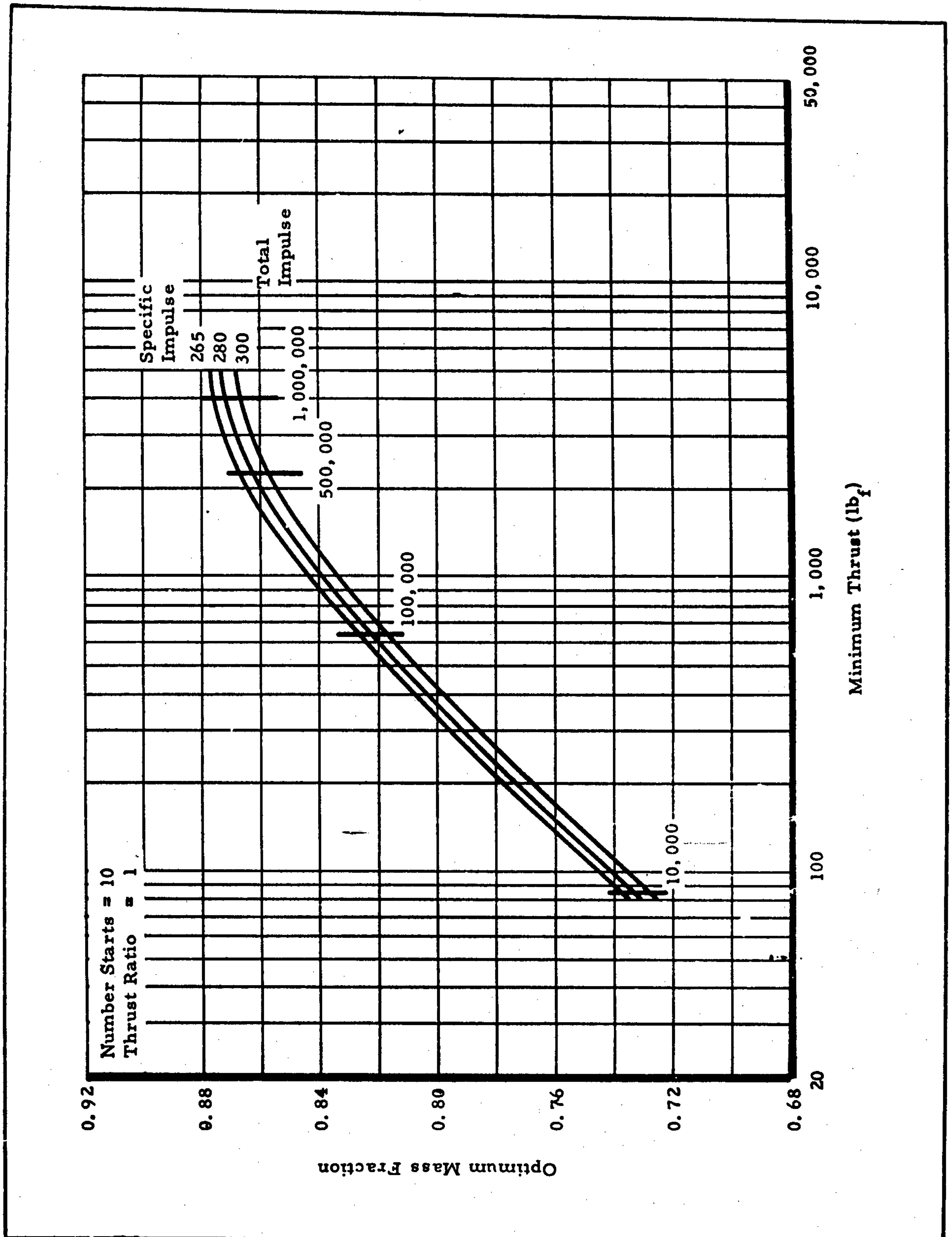

Figure 7 - Effect of Specific Impulse on Mass Fraction

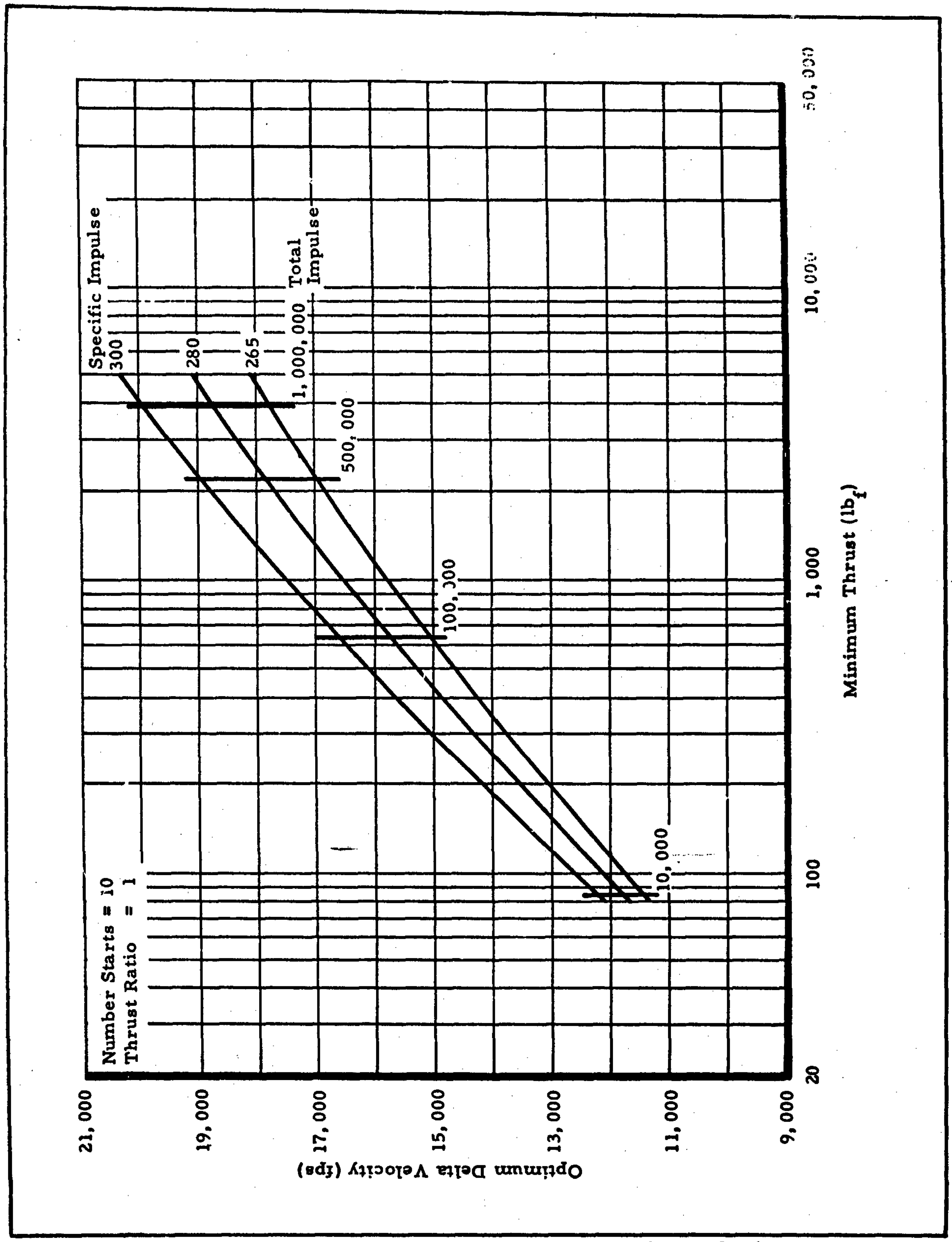

Figure 8 - Effect of Specific Impulse on Delta Velocity

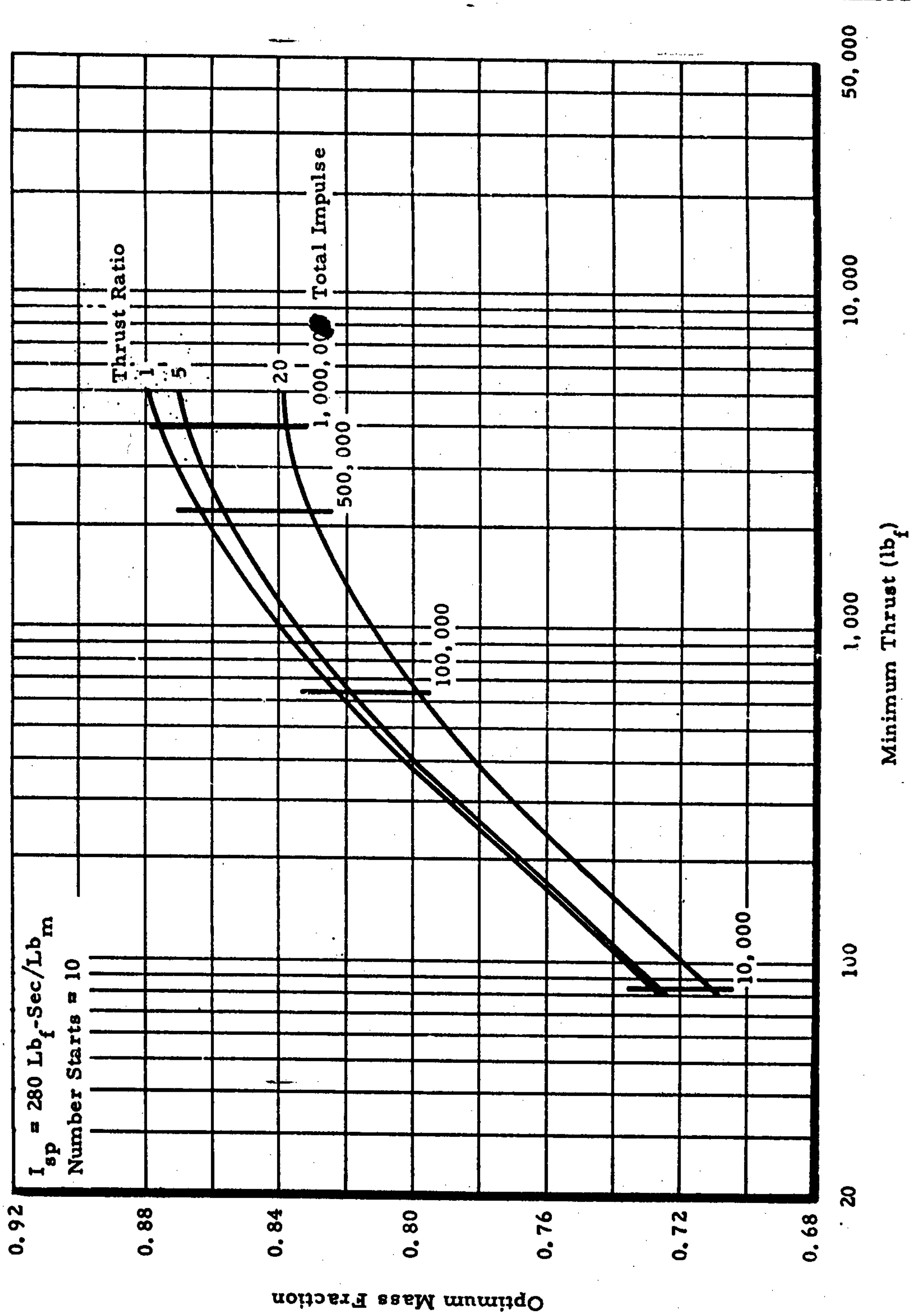

Figure 9 - Effect of Thrust Ratio on Mass Fraction

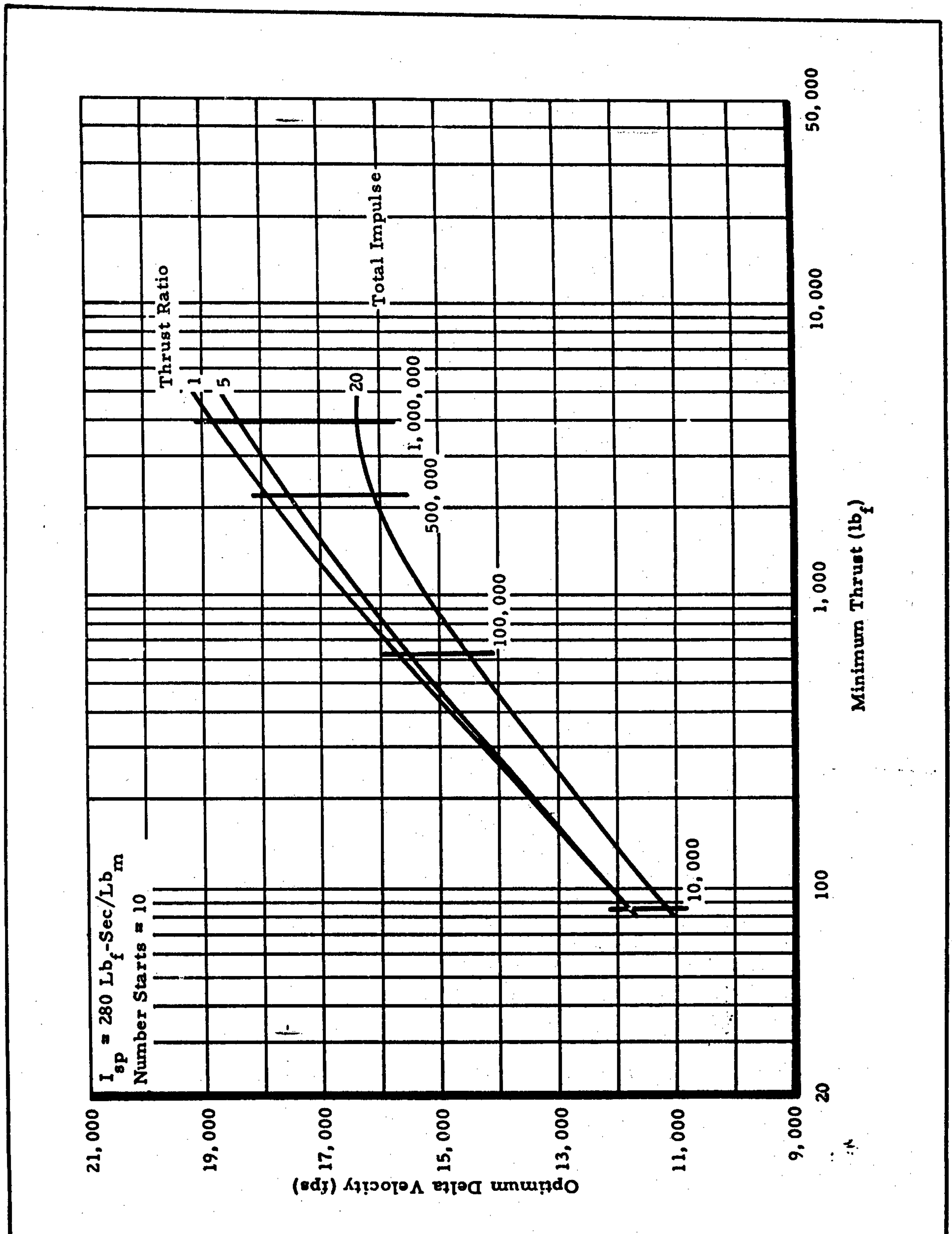

Figure 10 - Effect of Thrust Ratio on Delta Velocity

mass fraction and delta velocity is small. This penalty becomes more pronounced, however, for a thrust ratio of 20, particularly for the larger motors. For example, the mass fraction is decreased 2.7 percent at a 20-to-1 thrust ratio for a 10,000-lb-sec motor, compared to a decrease of 4.5 percent for a 1,000,000-lb-sec motor. This penalty is due to the effect of the higher chamber pressure, required for the 20-to-1 thrust ratio, on case thickness, resulting in a greater weight penalty in the large-diameter (high total impulse) motors. However, the 20-to-1 throttling range imposes very little penalty over that of a stop-restart motor alone (thrust ratio of 1) at the lower total impulse levels. (Confidential)

d. Number of Starts

The effects of the number of starts, for a restartable motor, on mass fraction and delta velocity are shown in Figures 11 and 12, respectively. The differences represent the weight penalty imposed by the multiple pyrogen units for restart capability. The weight of a valve for termination was included for all motor designs, including the motor with one start. The mass fraction penalty for 20 starts, compared to one start, is 1.8 percent for the 10,000-lb-sec motors, and 1.2 percent for the 1,000,000-lb-sec motors. (Confidential)

e. Total Impulse and Minimum Thrust

The effects of total impulse on mass fraction and delta velocity are shown in Figures 13 and 14, respectively, for motors with thrust ratios of 1, 5, and 20 to 1. The mass fraction for each total impulse level corresponds to that at the optimum minimum thrust level, derived from Figure B-5. Figure 15 is a contour map of mass fraction as a function of total impulse and minimum thrust for a thrust ratio of one. A similar plot for a thrust ratio of 20 is given in Figure 16. The dotted constant mass fraction lines in Figures 15 and 16 are extrapolated values. These plots give the optimum minimum thrust levels corresponding to various total impulse level motors. (Confidential)

Figure 17 shows the effects of minimum thrust and total impulse on motor diameter. The dotted lines connect the values for constant total impulse designs, and the solid lines connect values for motor designs with similar grain configurations.

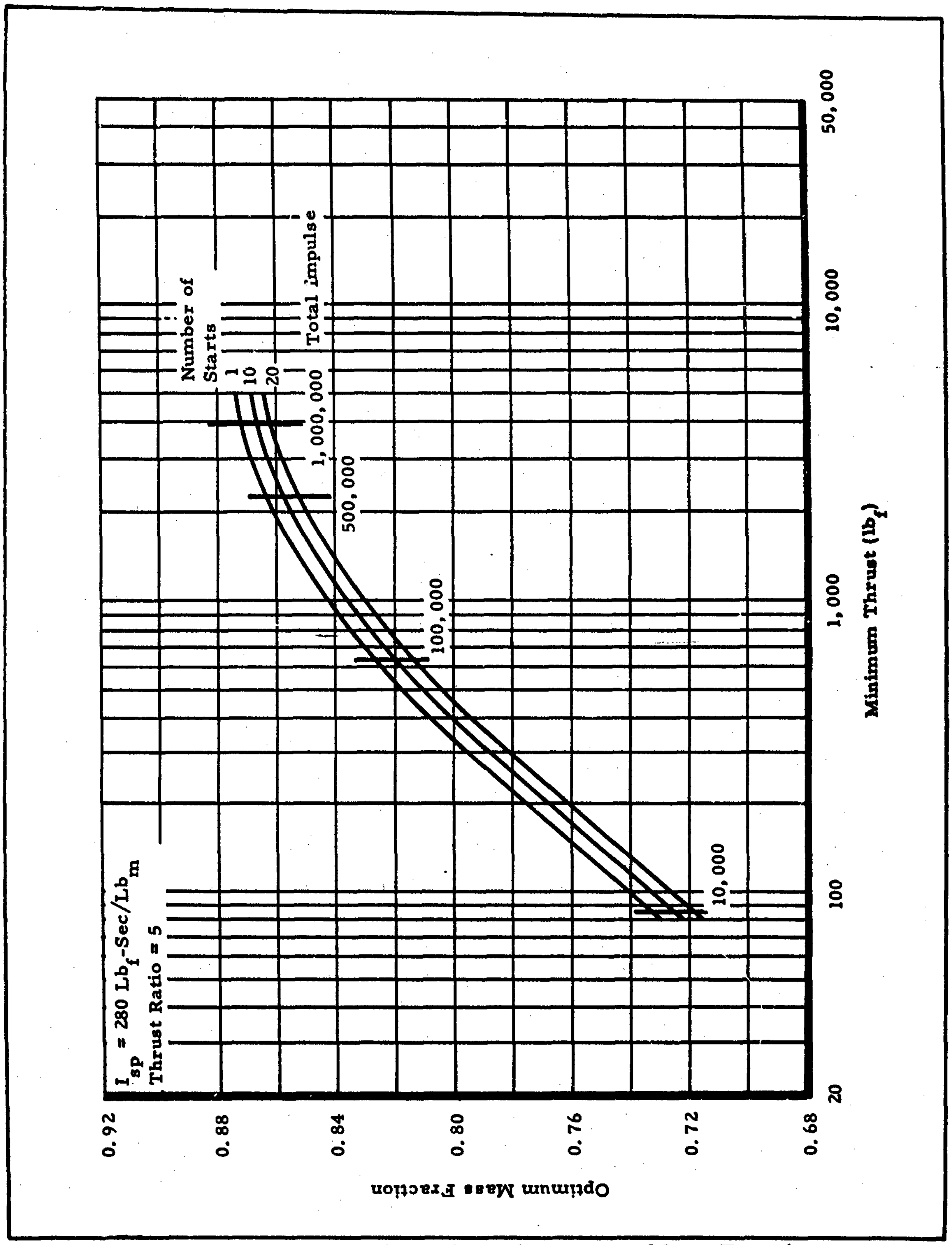

Figure 11 - Effect of Number of Starts on Mass Fraction

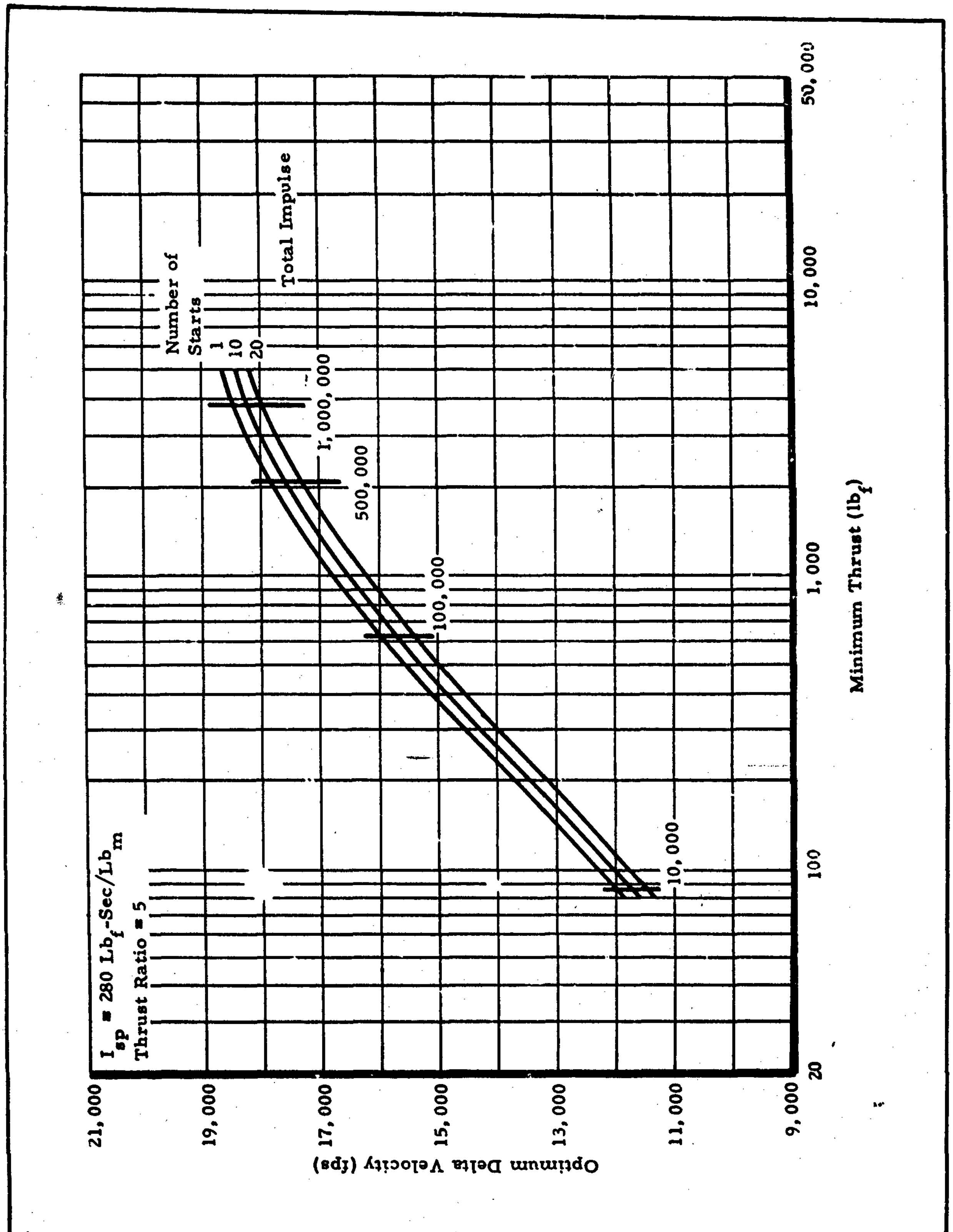

Figure 12 - Effect of Number of Starts on Delta Velocity

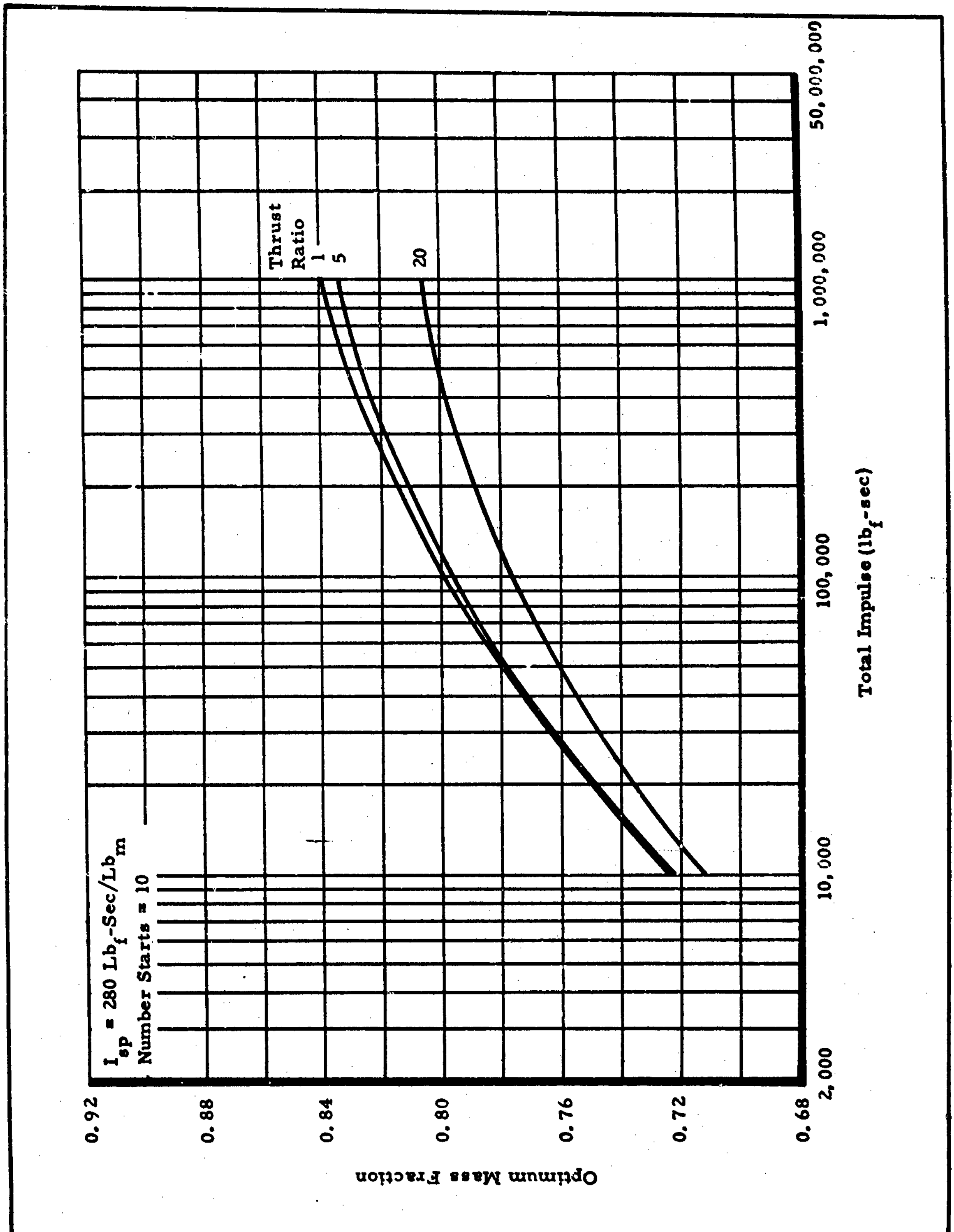

Figure 13 - Mass Fraction as a Function of Total Impulse

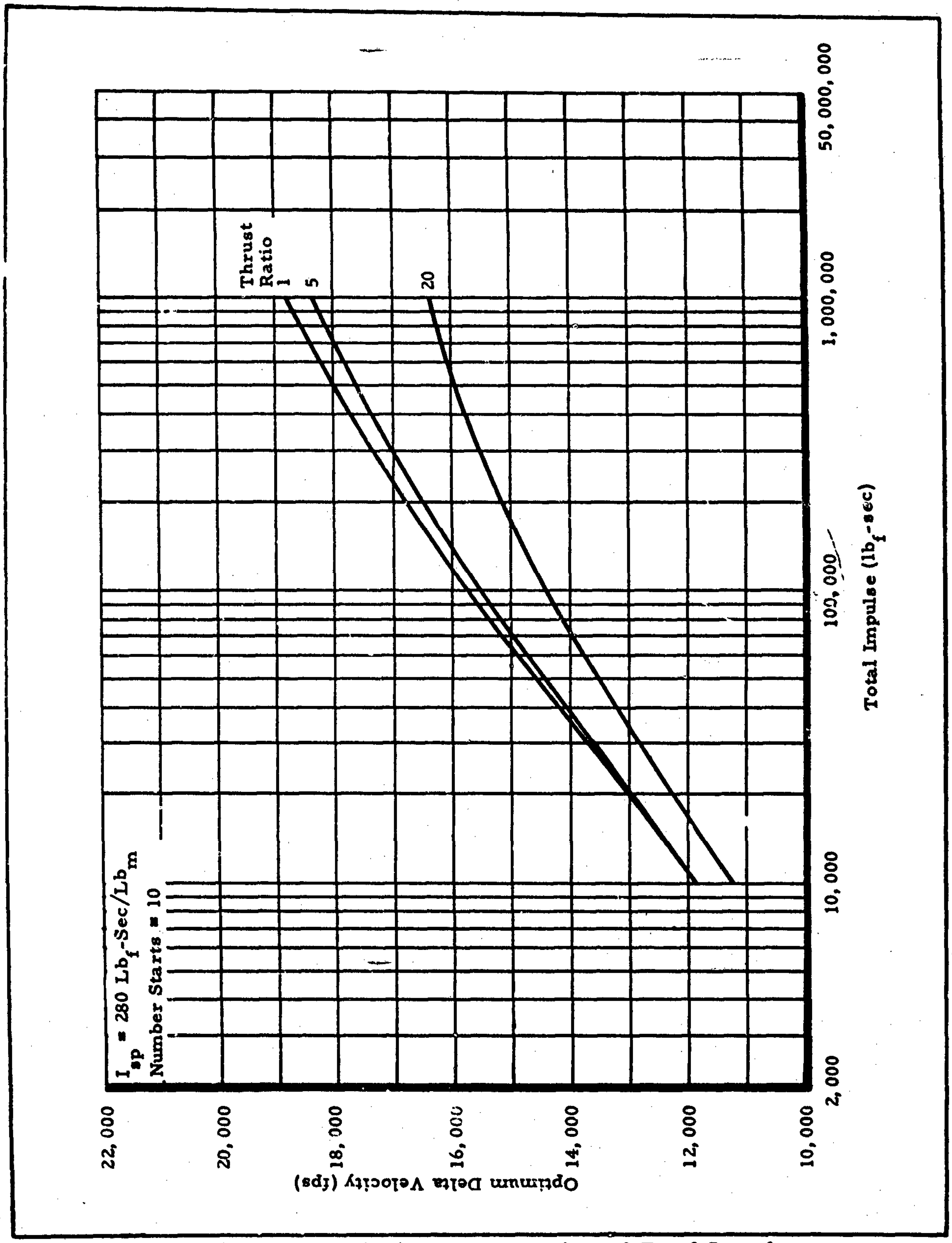

Figure 14 - Delta Velocity as a Function of Total Impulse

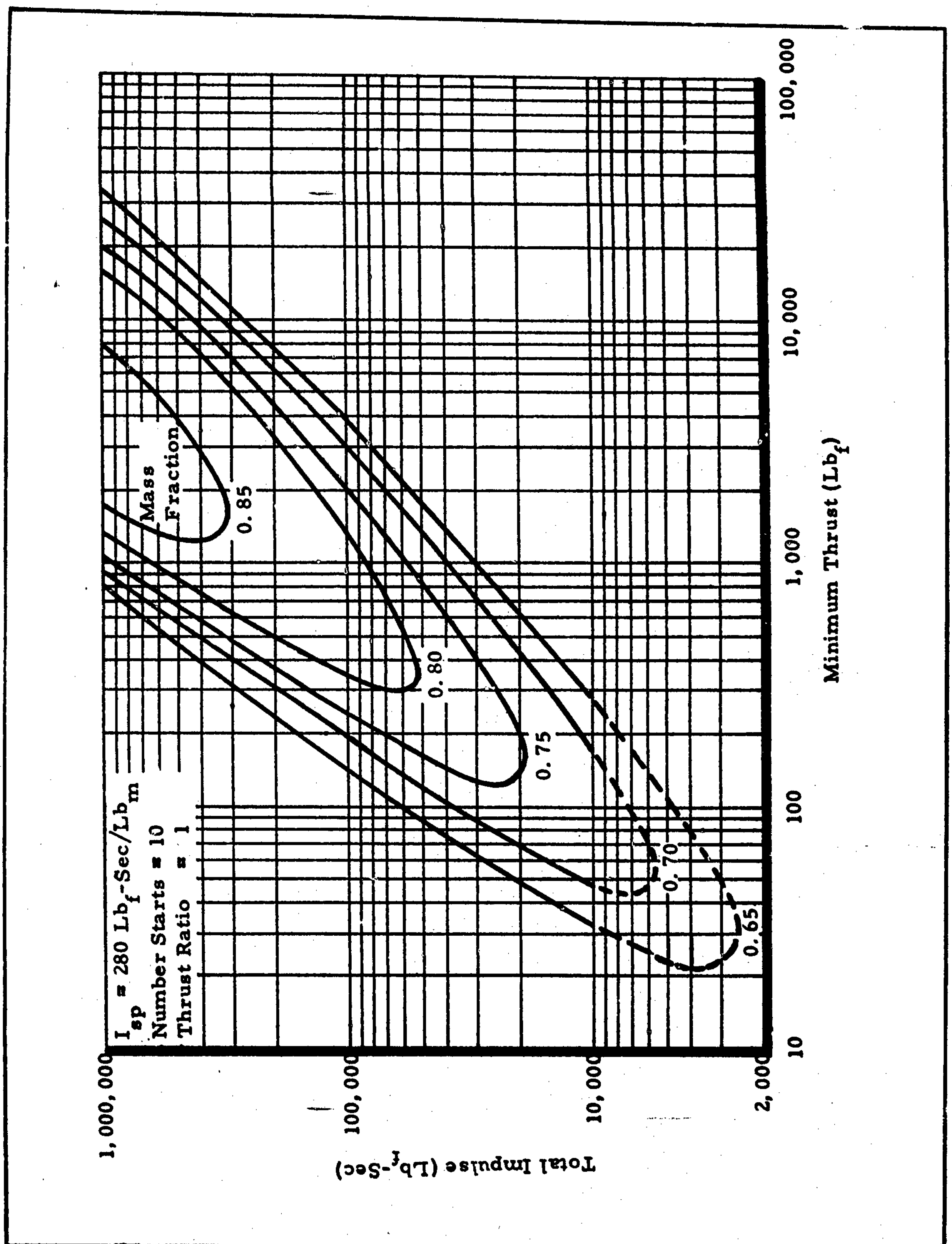

Figure 15 - Mass Fraction Contour Map for a Thrust Ratio of 1

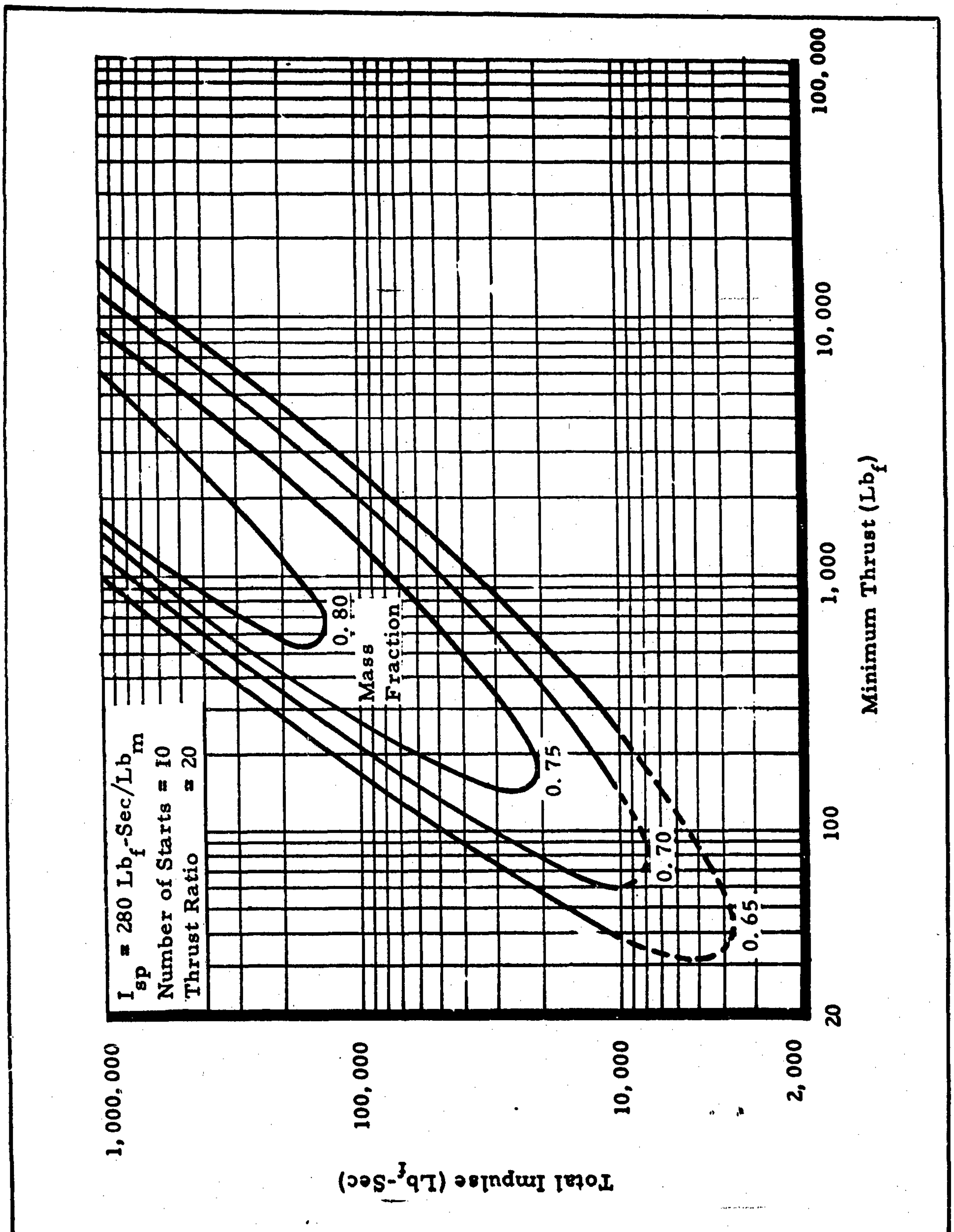

Figure 16 - Mass Fraction Contour Map for a Thrust Ratio of 20

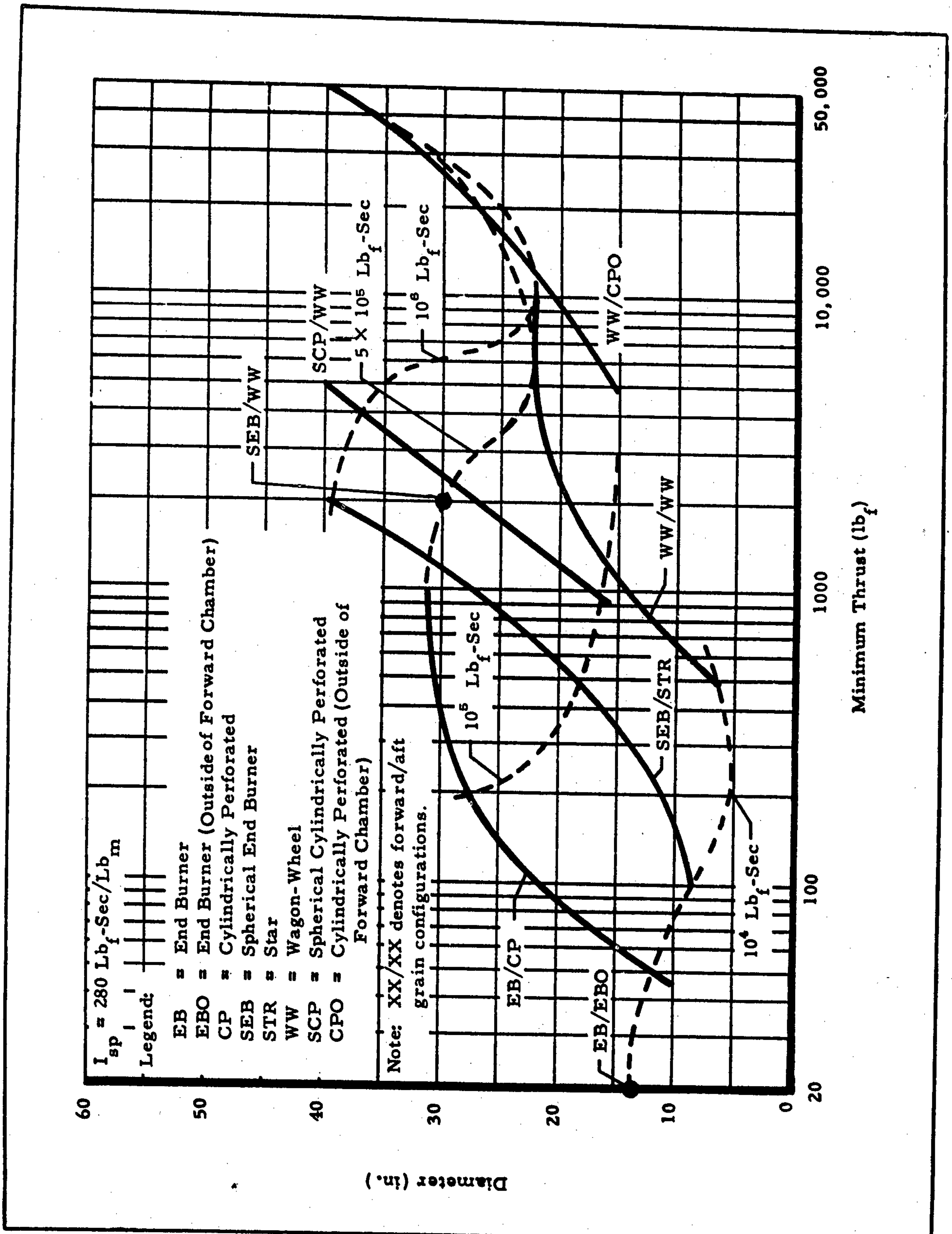

Figure 17 - Motor Diameter as a Function of Minimum Thrust and Total Impulse

A minimum diameter is obtained for each total impulse level motor at different minimum thrust levels. Note that the optimum minimum thrust level increases with increasing total impulse.

In Figure 18, the effects of total impulse and minimum thrust on motor length are shown; the dotted lines connect designs with similar grain configurations. This graph shows that total impulse affects grain length much less than minimum thrust. This is also borne out in Figure 19 in which the band of motor length is plotted as a function of minimum thrust.

3. PHASE II

a. General

The results of Phase II, in which case material, burning rate constants, pressure exponents, and weight flow ratios were investigated, are presented in the following paragraphs.

b. Case Material

Three case materials, fiberglass, titanium, and steel, were investigated in Phase IIa. The effect of the mass fraction ratio of fiberglass to steel motors and titanium to steel motors as a function of minimum thrust is shown in Figure 20 for 100,000-lb-sec total impulse motors. The effect of delta velocity ratio for these same conditions is shown in Figure 21. The advantages of fiberglass and titanium over steel become more significant at the higher thrust levels. (Confidential)

The effects of case material on mass fraction and delta velocity as a function of thrust ratio are presented in Figures 22 and 23, respectively. As thrust ratio increases, which corresponds to higher chamber pressures, the effect of the three materials on mass fraction and delta velocity becomes more pronounced. (Confidential)

c. Burning-Rate Constants

The effects of forward- and aft-propellant burning-rate constants on optimum mass fraction and optimum delta velocity are shown in Figures 24 and 25, respectively, for 100,000-lb-sec motors. For this motor size the highest forward rate constant

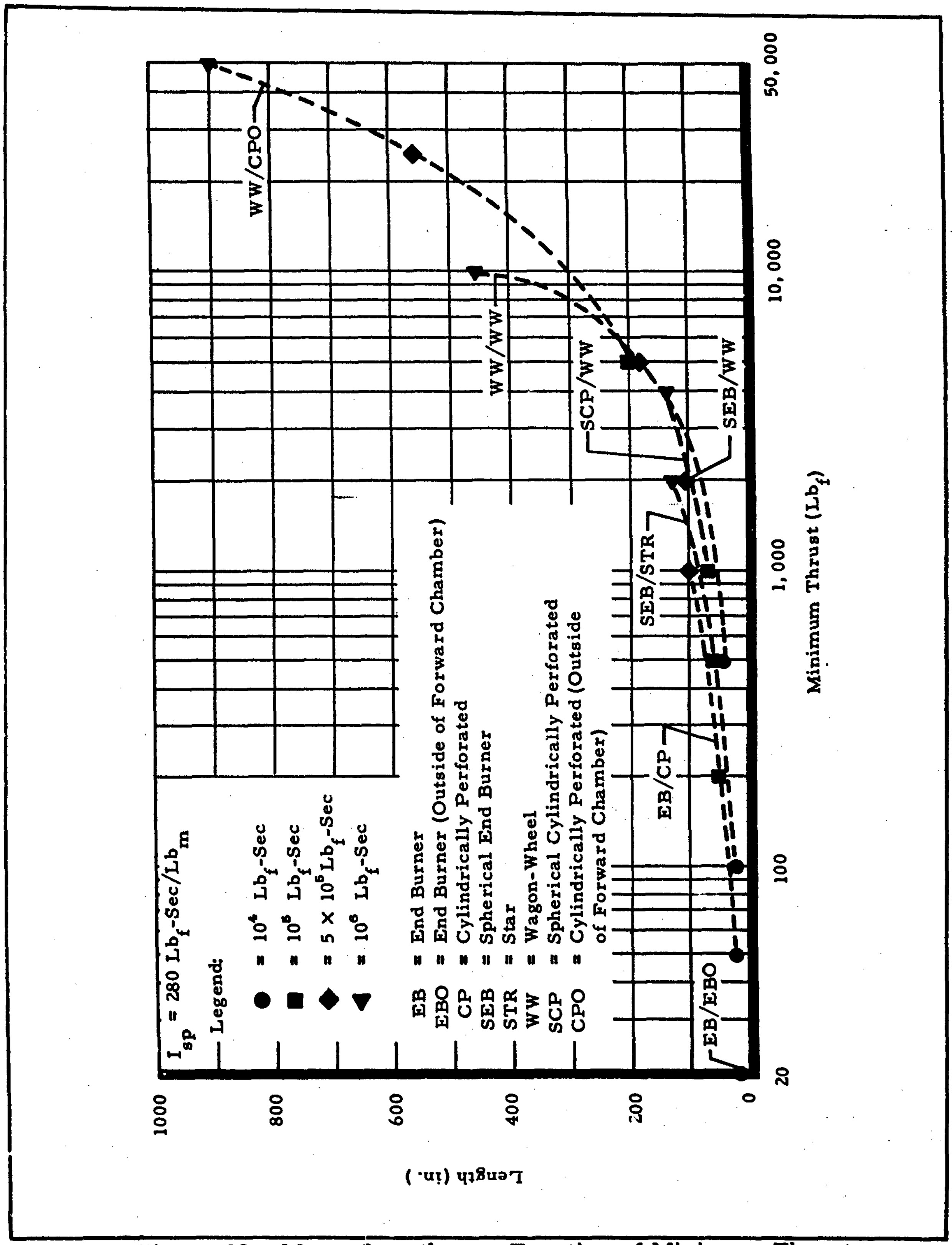

Figure 18 - Motor Length as a Function of Minimum Thrust and Total Impulse

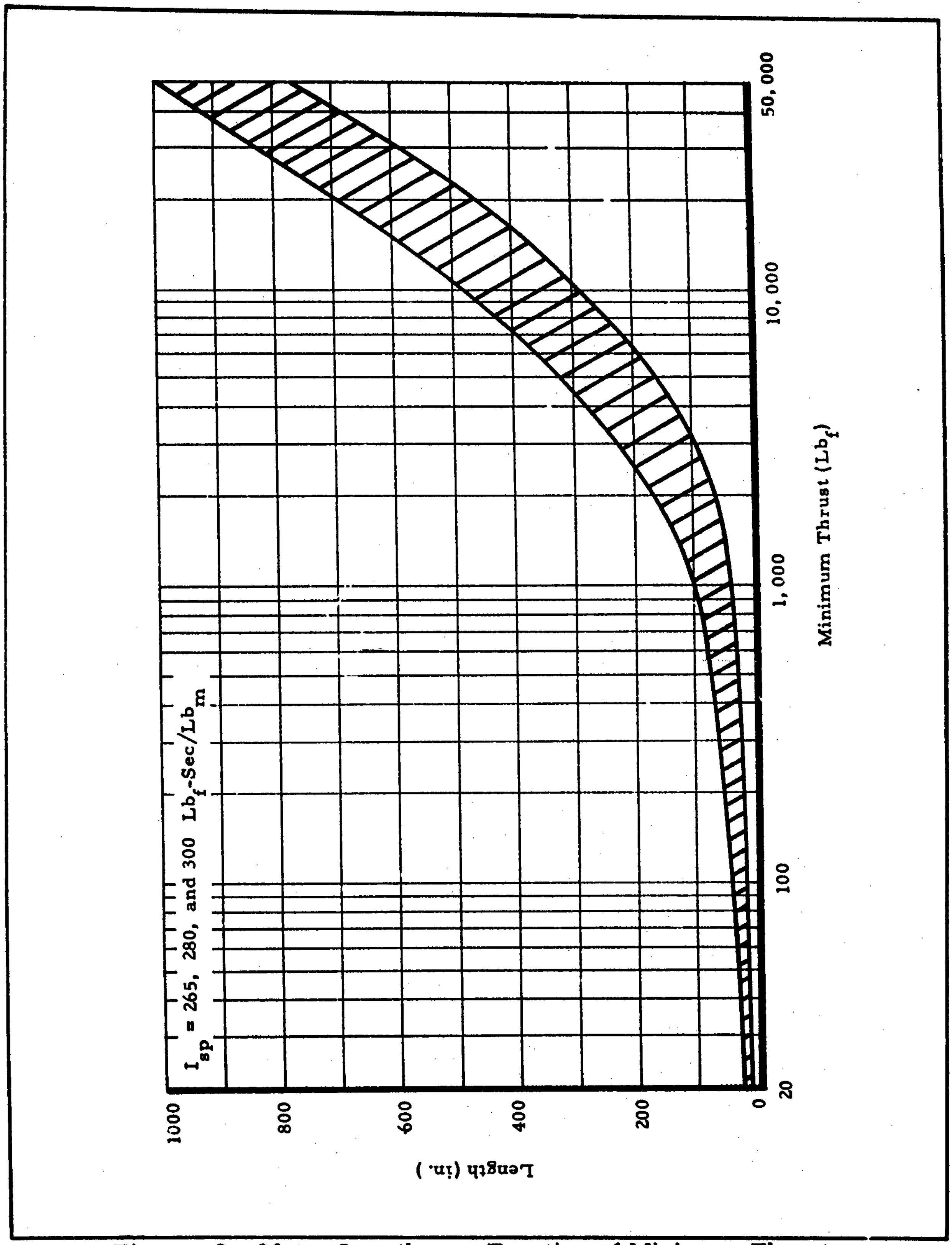

Figure 19 - Motor Length as a Function of Minimum Thrust

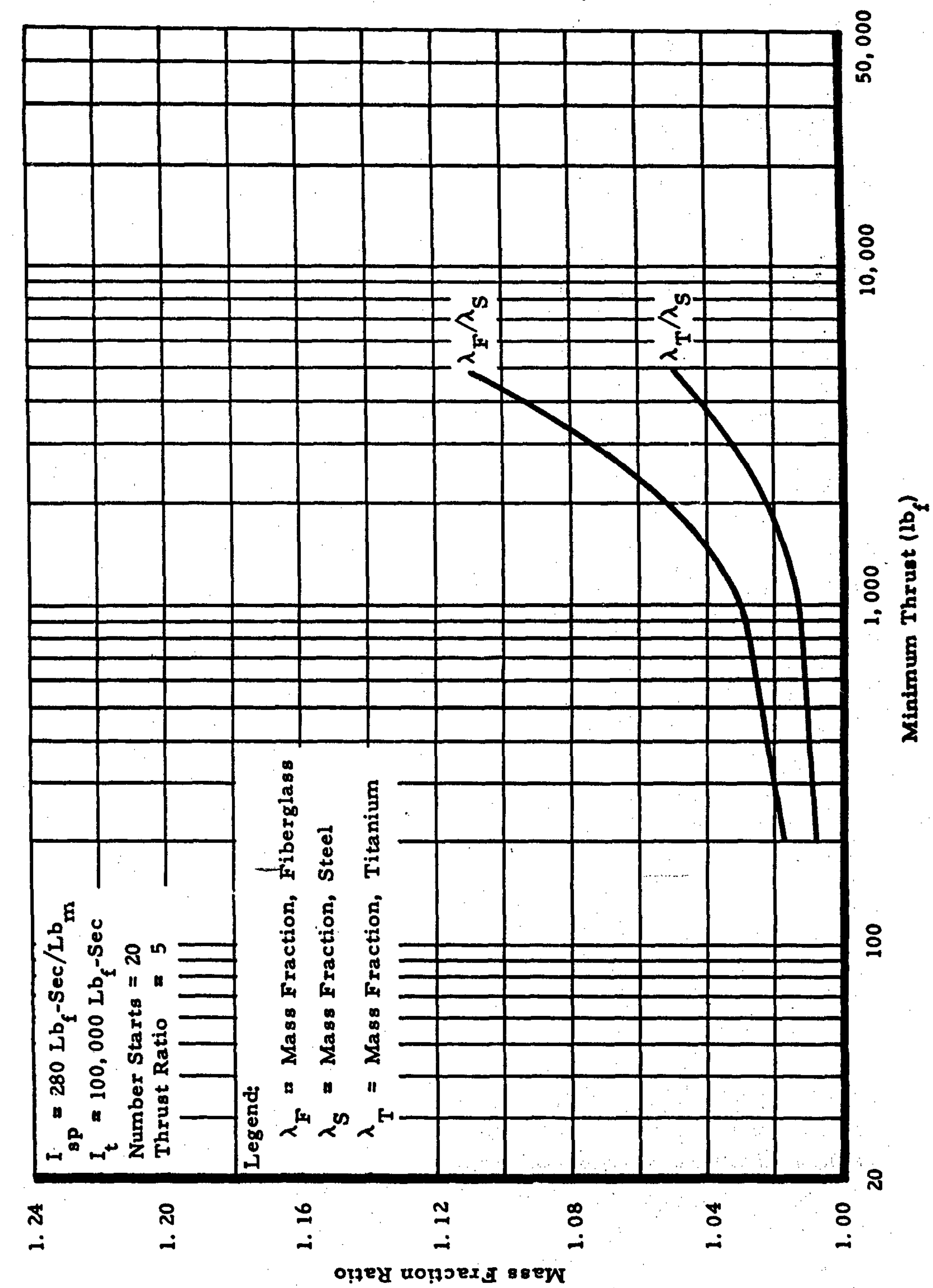

Figure 20 - Effect of Case Material on Mass Fraction

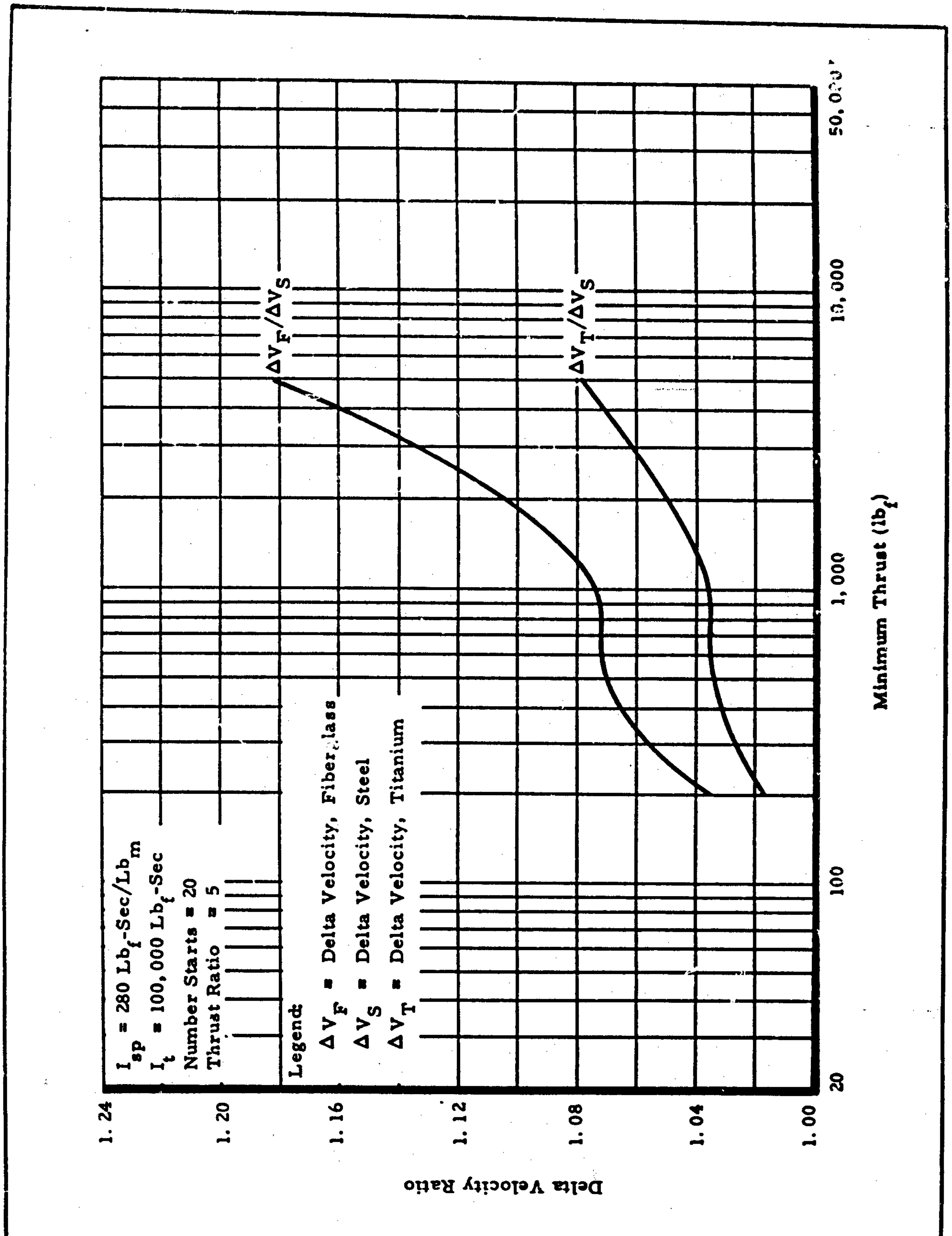

Figure 21 - Effect of Case Material on Delta Velocity

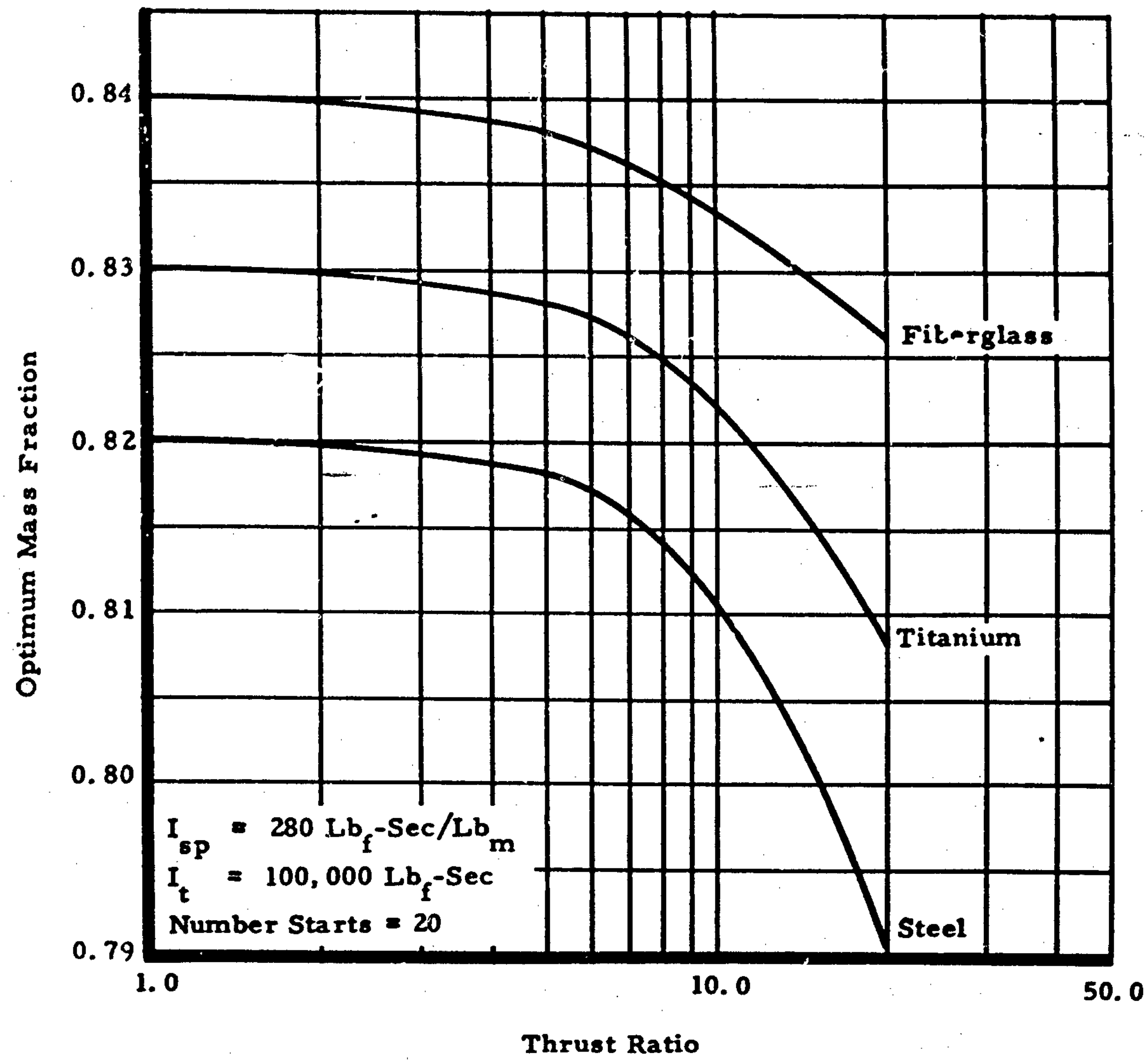

Figure 22 - Mass Fraction as a Function of Thrust Ratio for Three Case Materials

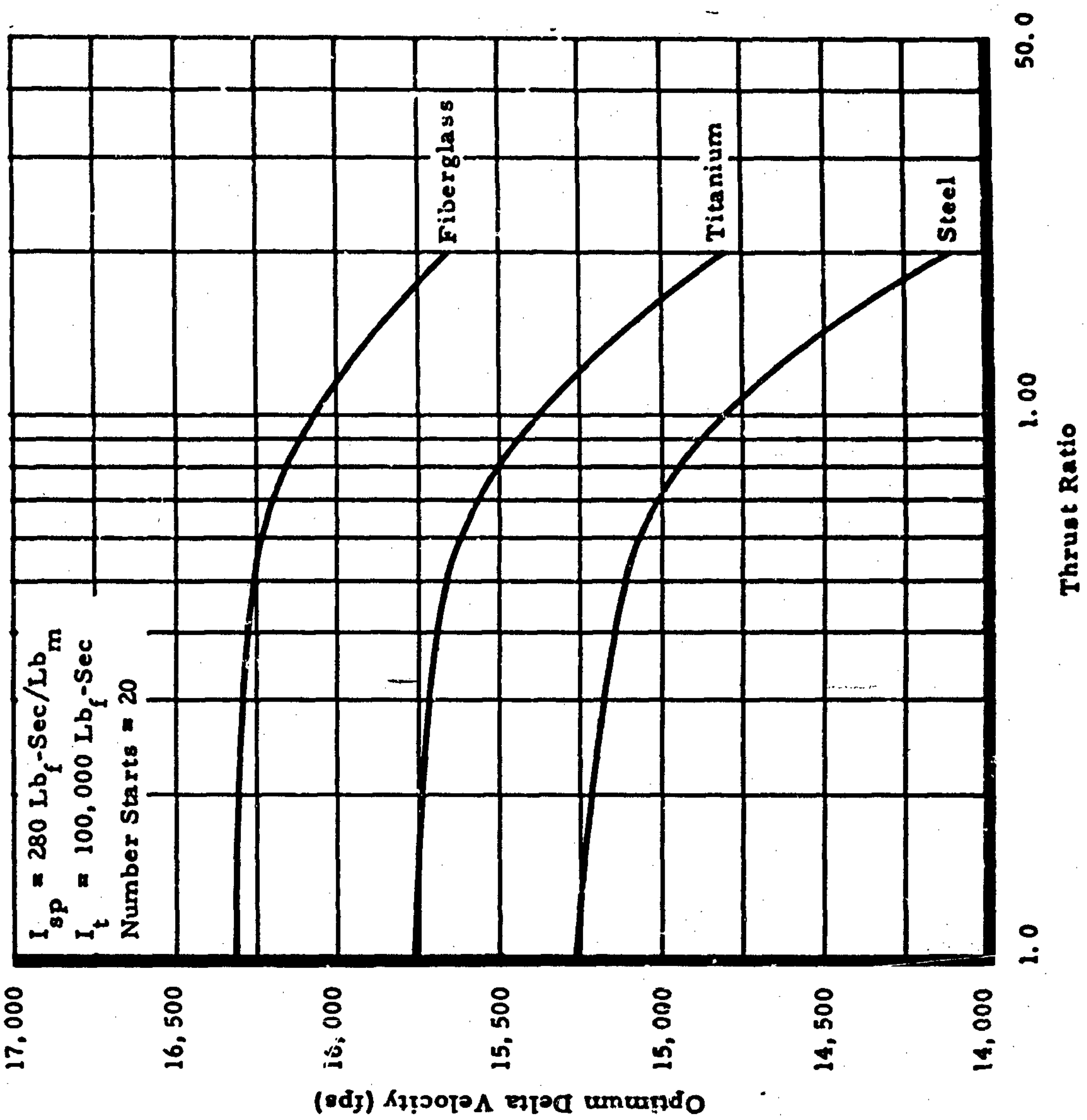

Figure 23 - Delta Velocity as a Function of Thrust Ratio for Three Case Materials

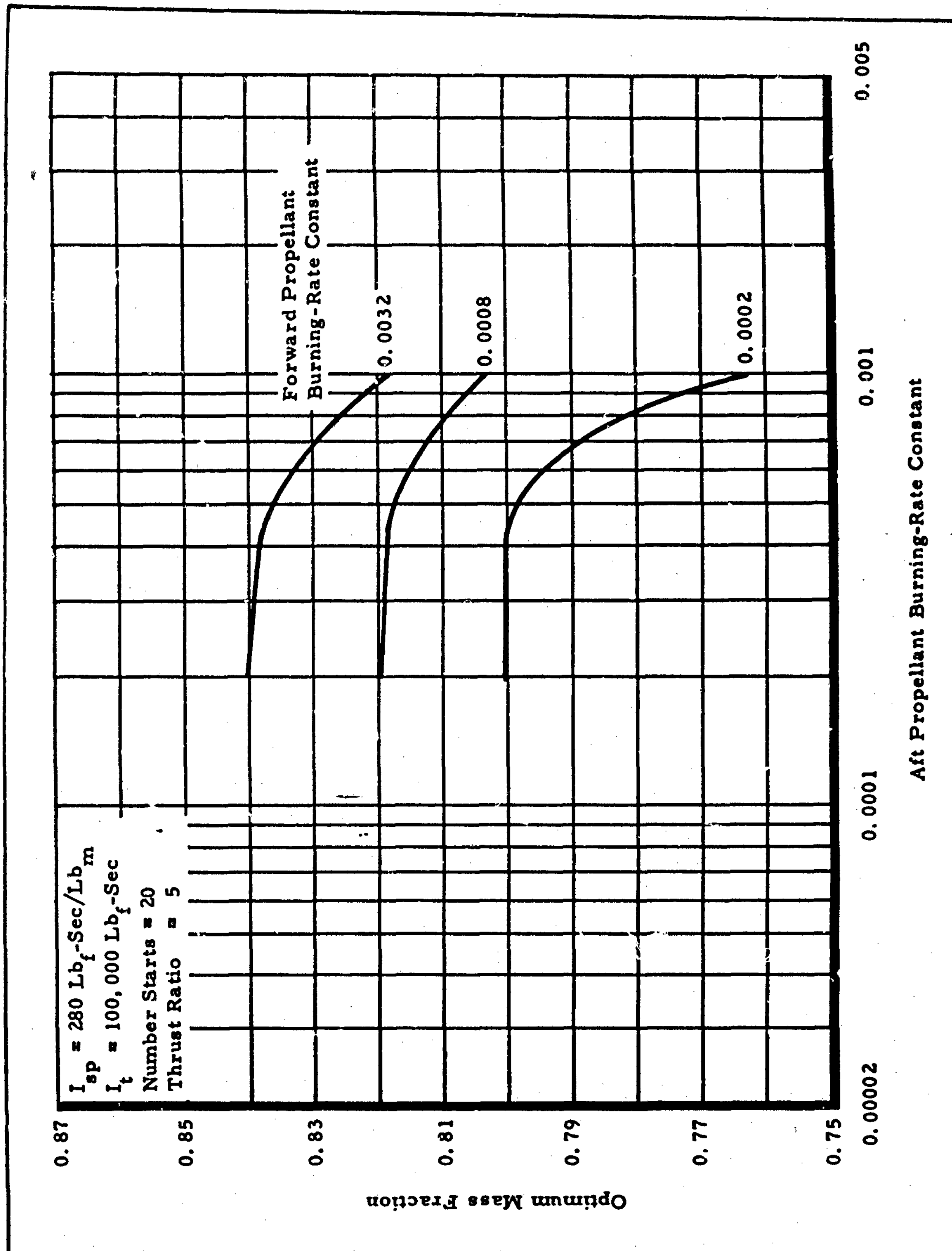

Figure 24 - Effect of Burning-Rate Constants on Mass Fraction

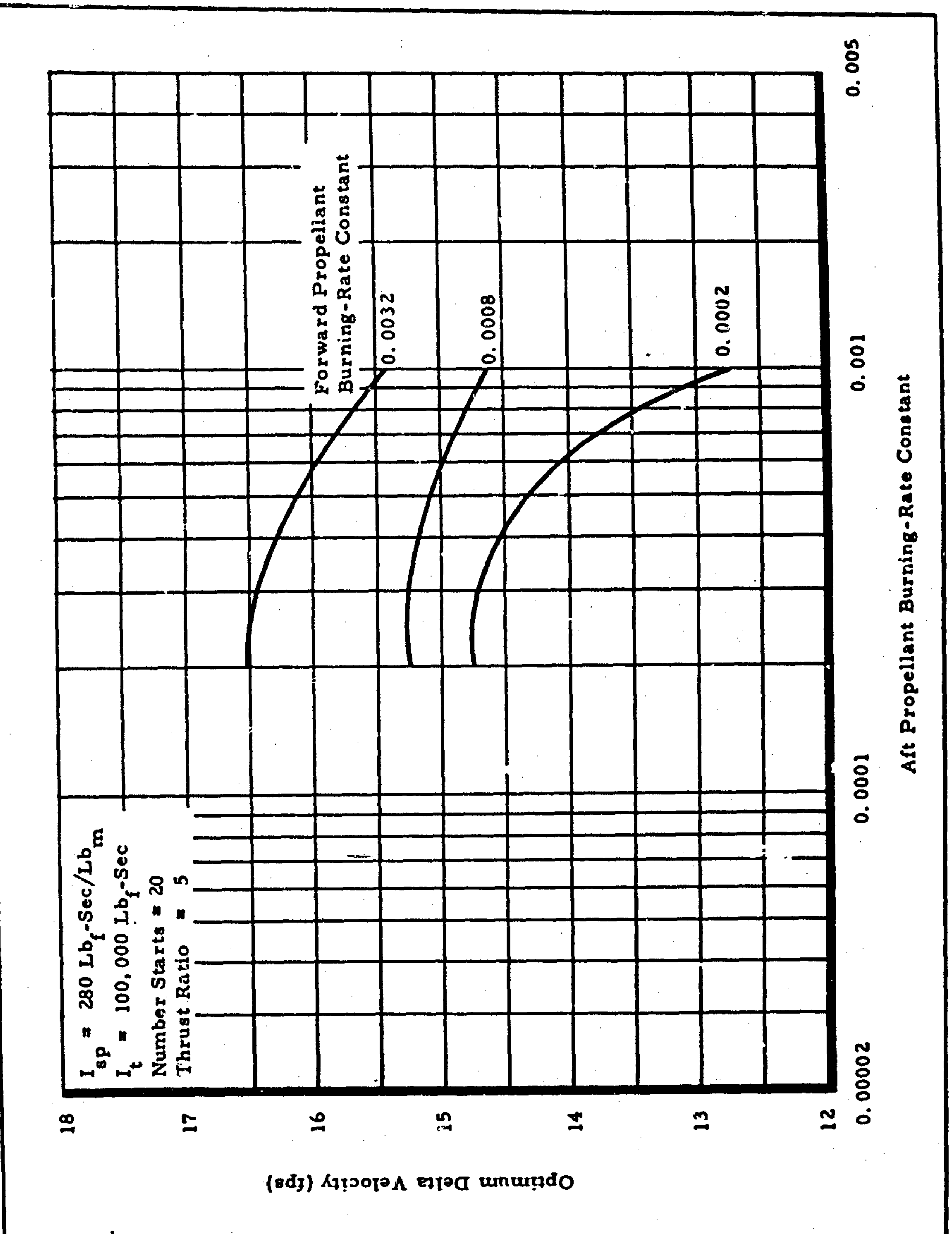

Figure 25 - Effect of Burning-Rate Constants on Delta Velocity

and lowest aft rate constant investigated produced the highest mass fraction and boost velocity. These constants gave motor designs with smaller diameters than others, as shown in Appendix B. The higher forward rate constant permitted an end-burning forward-grain configuration to be used, while the lower aft rate constant allowed a star aft-grain configuration to be employed. These optimum mass fraction and delta velocity values were calculated at a minimum thrust of 500 lb_f. At lower minimum thrust values, lower forward rate constants were more advantageous. (Confidential)

d. Pressure Exponents

As expected, the higher burning-rate pressure exponents give higher mass fractions and boost velocities for throttleable motors, as shown in Figures 26 and 27. At a thrust ratio of 20, the effects of forward and aft exponents are very pronounced. For example, as the forward exponent increases from 0.60 to 0.90 and the aft exponent changes from 0.80 to 1.00 (Figure 26), mass fraction increases from 0.52 to 0.81. For a thrust ratio of 5 to 1, on the other hand, the effect of the exponents is very slight. (Confidential)

e. Aft-to-Forward Weight Flow Ratio

The effects of aft to forward weight flow ratio (θ) on mass fraction and delta velocity are shown in Figures 28 and 29, respectively. The higher θ values are advantageous because, at these conditions, the aft chamber operates at a lower pressure than the forward chamber and has a higher aft propellant density. A θ of 4 produces less than a 4-percent increase in mass fraction over a θ of 2, but provides a 7.5-percent increase in delta velocity (Confidential)

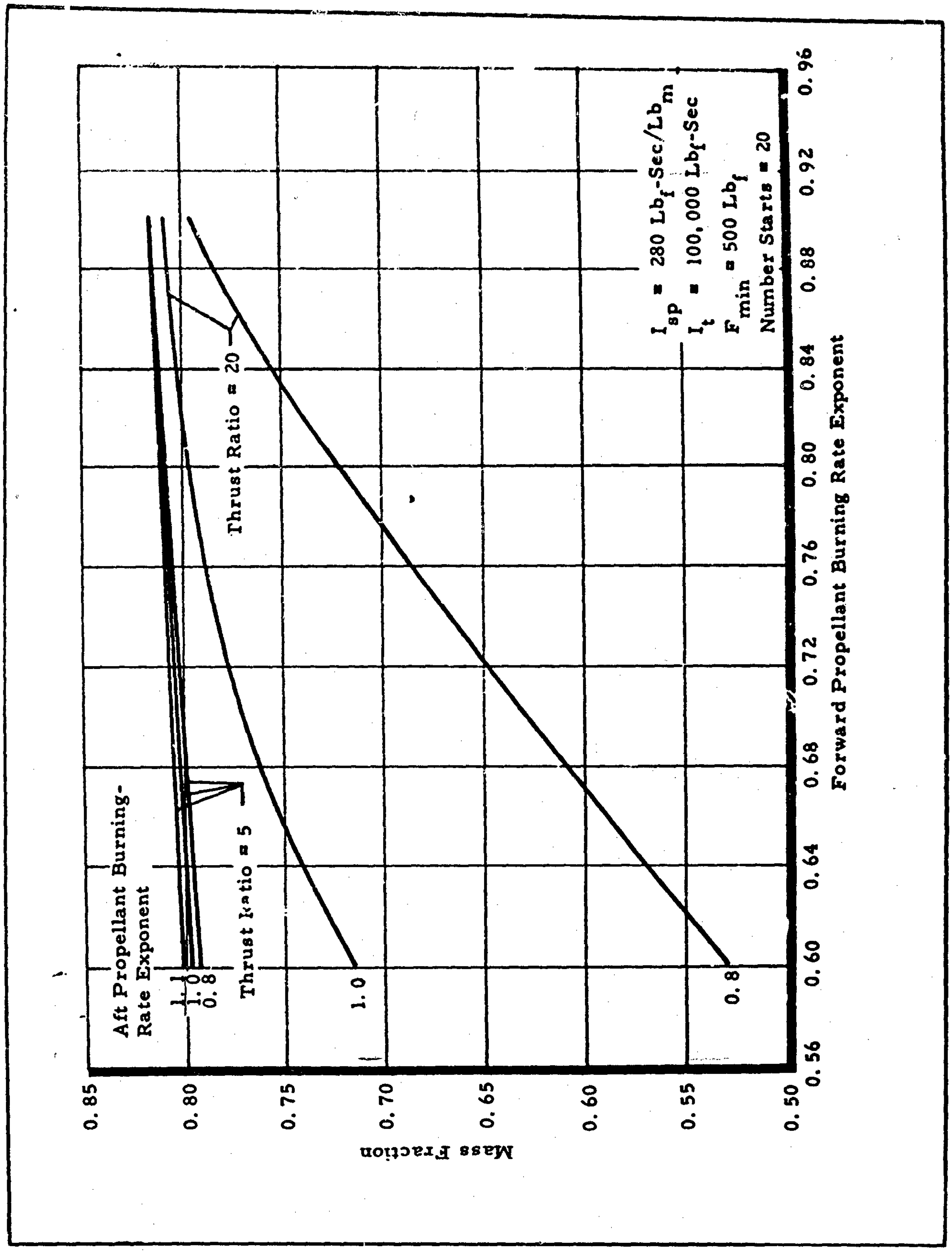

Figure 26 - Effect of Burning-Rate Pressure Exponents on Mass Fraction

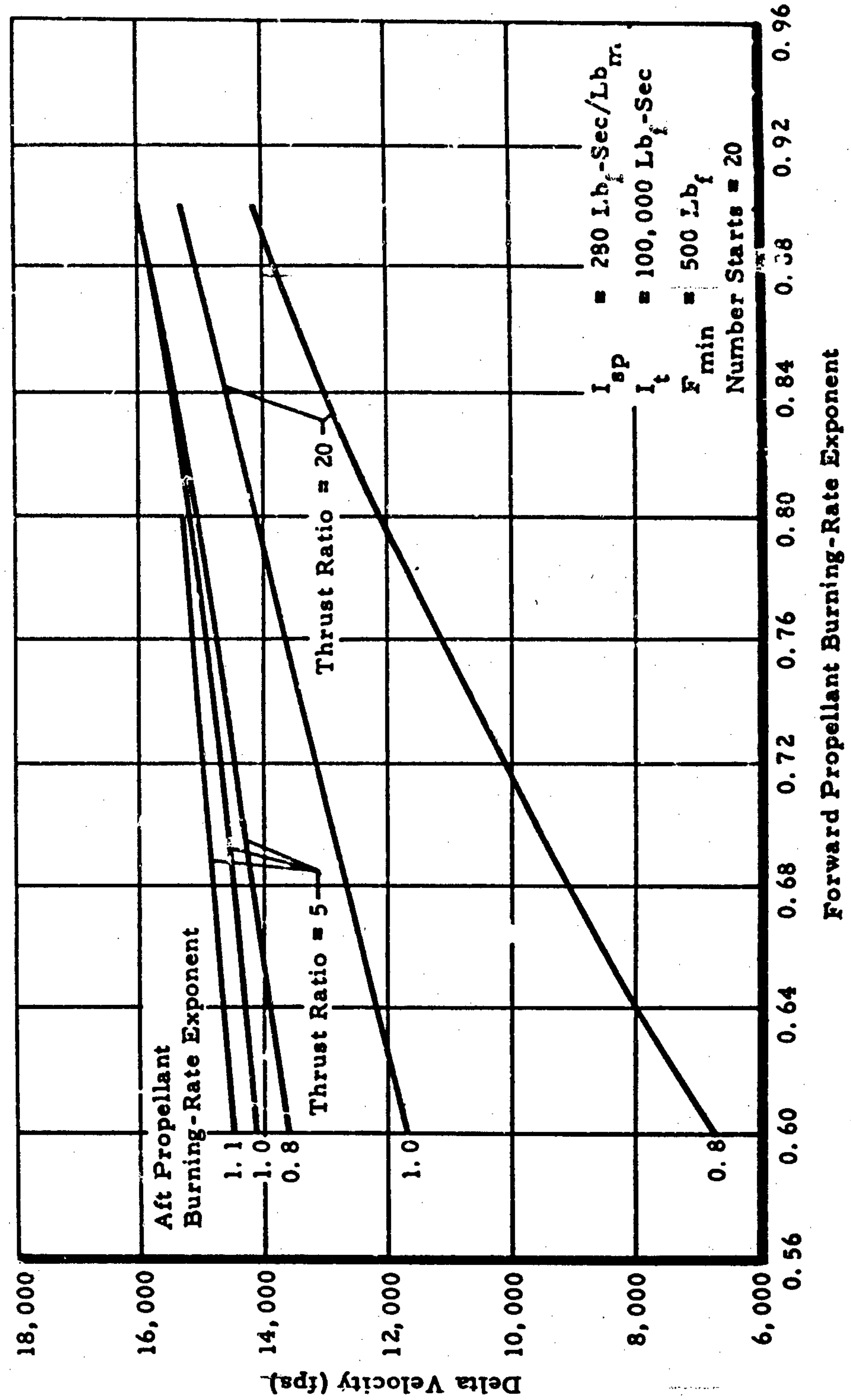

Figure 27 - Effect of Burning-Rate Pressure Exponents on Delta Velocity

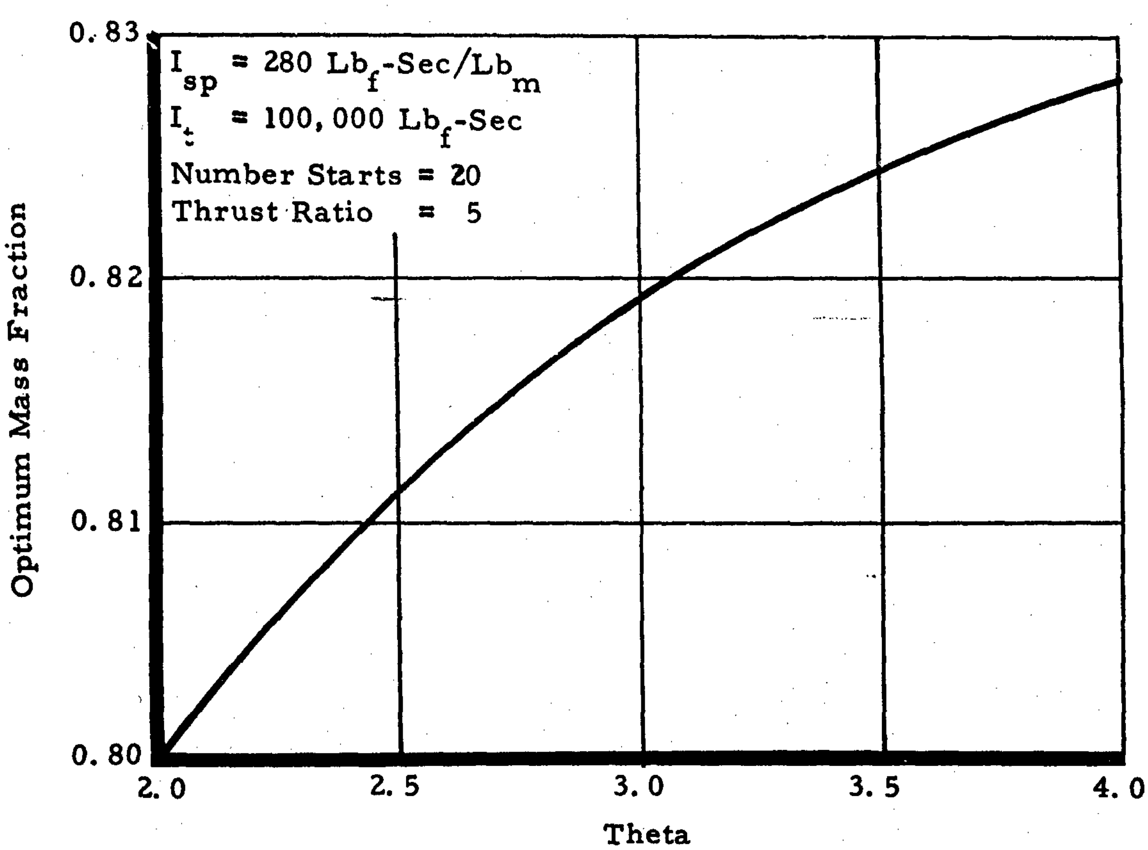

Figure 28 - Effect of θ on Mass Fraction

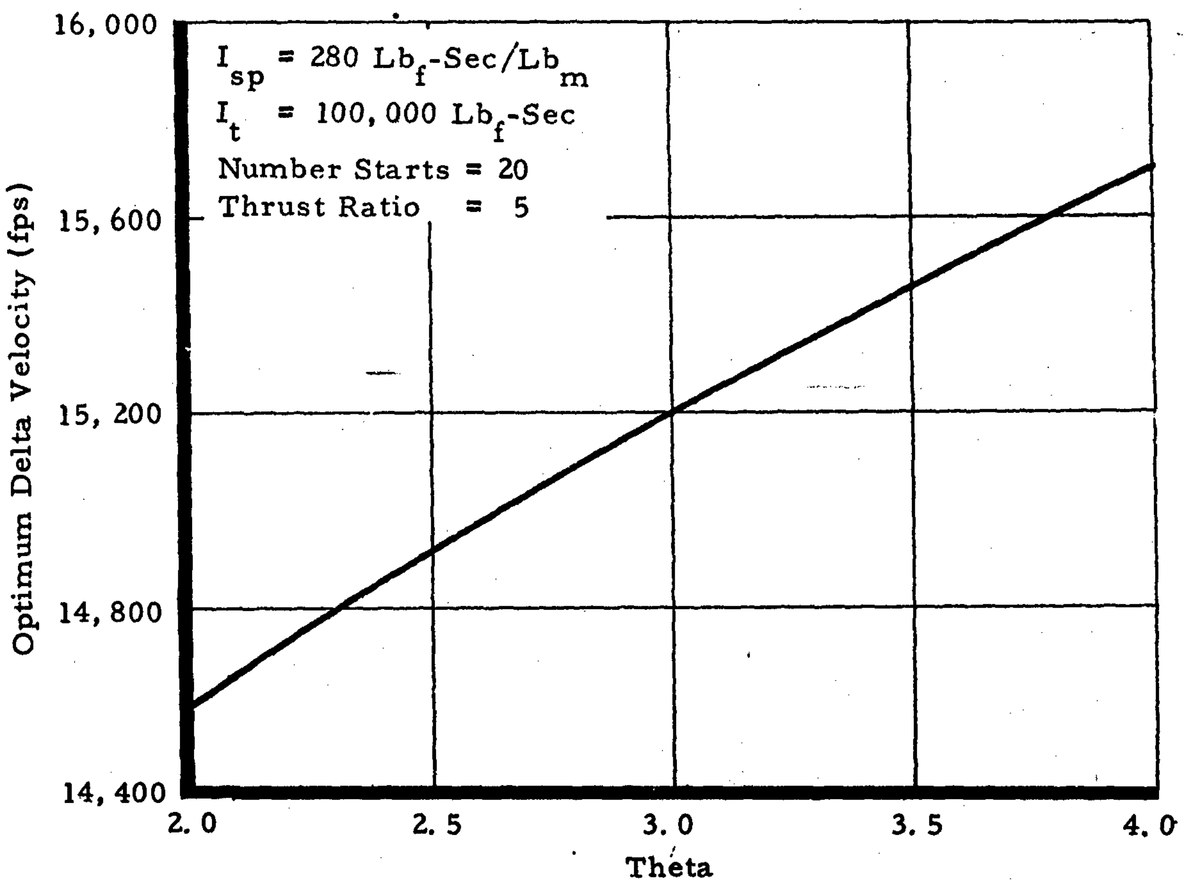

Figure 29 - Effect of θ on Delta Velocity

SECTION IV - SUMMARY

Although the performance values for mass fraction, delta velocity, and envelope generated in this study are not intended to represent those that would be obtained from detailed designs, the values agree fairly well with those previously calculated in detail for individual motors.

It was found that, by increasing specific impulse, mass fraction is reduced but delta velocity and total motor weight are increased. For 10,000-lb-sec motors, an increase in specific impulse from 265 to 300 lb-sec/lb increased delta velocity by 7 percent, whereas for 1,000,000-lb-sec motors, the increase was 12 percent. (Confidential)

The mass fraction penalty imposed by a 20-to-1 thrust modulation was 2.5 percent for low-impulse (10,000 lb-sec), low-thrust (100 lb_f) motors. This penalty increased to above 4 percent as impulse increased to 1,000,000 lb-sec and thrust to 4,000 lb_f. These values were based on the characteristics of available propellants. Improved propellant pressure exponents would reduce the penalties. (Confidential)

For motors having stop-restart capability (that is, an on-off valve), the number of restarts available had little effect on mass fraction and delta velocity. The mass fraction penalty for additional igniters was less than 0.1 percent per restart.

At each impulse level, there was an optimum thrust range for throttleable motors which was close to the optimum thrust level for non-throttling motors. If the thrust was increased or decreased beyond this range, both mass fraction and delta velocity decreased.

Fiberglass and, to a lesser degree, titanium were found to be very advantageous for motor case materials, compared to steel, for motors with high thrust levels and high throttling requirements.

The highest forward propellant burning-rate constant and lowest aft propellant burning-rate constant investigated gave the highest mass fraction and delta velocity values for the 100,000-lb-sec motor size.

Mass fraction was more sensitive to forward and aft propellant pressure exponents than to any other propellant characteristics at high

[redacted]

throttling ratios. Aft propellant pressure exponent significantly affected mass fraction for motors with low forward exponents. However, with high forward exponents, the effect of the aft exponent was much less. Conversely, forward exponent change is less significant with high aft exponents. (Confidential)

Increasing the aft-to-forward grain weight flow ratio from 2 to 4, for the 100,000-lb-sec motor size, increased mass fraction from 0.80 to 0.83. (Confidential)

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2. APR-7-2: Development of an Intermittent Operating Variable Thrust Solid Propellant Rocket Motor (U). (Second Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, October 1962. (Confidential Report)

3. APR-7-3: Development of an Intermittent Operating Variable Thrust Solid Propellant Rocket Motor (U). (Third Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, January 1963. (Confidential Report)

4. APR-7-4: Development of an Intermittent Operating Variable Thrust Solid Propellant Rocket Motor (U). (First Annual Report - Fiscal Year 1962). RPL-TDR-63-1061. Amcel Propulsion Company, Asheville, North Carolina, December 1963. (Confidential Report)

5. APR-21-1: Controllable Solid Propellant Rocket Motor (U). (First Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, June 1963. (Confidential Report)

6. APR-21-2: Controllable Solid Propellant Rocket Motor (U). (Second Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, September 1963. (Confidential Report)

7. APR-21-3: Controllable Solid Propellant Rocket Motor (U). (Third Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, December 1963. (Confidential Report)

8. APR-21-5: Dual-Chamber Controllable Solid Propellant Rocket Motor (U). (Fourth Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, May 1964. (Confidential Report)

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9. APR-21-6: Dual-Chamber Controllable Solid Propellant Rocket Motor (U). (Fifth Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, August 1964. (Confidential Report)

10. APR-21-7: Dual-Chamber Controllable Solid Propellant Rocket Motor (U). (Sixth Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, November 1964. (Confidential Report)

11. APR-21-8: Dual-Chamber Controllable Solid Propellant Rocket Motor (U). (Seventh Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, February 1965. (Confidential Report)

12. APR-21-9: Dual-Chamber Controllable Solid Propellant Rocket Motor (U). (Eighth Quarterly Report). Amcel Propulsion Company, Asheville, North Carolina, September 1965. (Confidential Report)

13. APR-21-4: Controllable Solid Propellant Rocket Motor (U). (Second Annual Report - Fiscal Year 1963). RPL-TDR-64-52. Amcel Propulsion Company, Asheville, North Carolina, September 1964. (Confidential)

APPENDIX A - COMPUTER PROGRAMS

A printout of the entire computer program is presented on the following pages. The program is arranged by subroutine in the sequence shown in Figure 1. The individual subroutines are shown in more detail in Figures 2, 3, 5, and 6, respectively.

```
-6600  C       CSR  STEADY STATE BALLISTIC PROGRAM, FOR PARAMETRIC STUDY
-6600  C       DR. ALLEY  M.K. OPPRECHT    AUGUST 1964
-6600  C       REVISION BY W. OSTERHOUT  OCTOBER 1,1964
-6600  C
-6600  C
-6600  C     C(1) IS CODE 1 = CODE FOR OPERATION OF STEADY STATE PROGRAM
-6600  C     C(2) IS CODE 2  = CODE FOR OPERATION OF GRAIN CONFIGURATION PROGRAM
-6600  C     C(3) IS RHOF = FWD. PROP. DENSITY
-6600  C     C(4) IS ALPF = FWD. PROP. BURN RATE CONSTANT
-6600  C     C(5) IS ENPF = FWD. PROP. EXPONENT
-6600  C     C(6) IS RHOA = AFT. PROP. DENSITY
-6600  C     C(7) IS ALPA = AFT PROP. BURN RATE CONSTANT
-6600  C     C(8) IS ENPA = AFT PROP. EXPONENT
-6600  C     C(9) IS CDF = FWD. PROP. CD
-6600  C     C(10) IS DELPF = DELTA FWD PRESSURE
-6600  C     C(11) IS FMN = MINIMUM THRUST
-6600  C     C(12) IS FMX = MAXIMUM THRUST
-6600  C     C(13) IS PFMN = FWD CHAMBER MINIMUM PRESSURE
-6600  C     C(14) IS THEPR = THETA PRIME
-6600  C     C(15) IS PAMN = AFT CHAMBER MINIMUM PRESSURE
-6600  C     C(16) IS XIPR = TOTAL IMPULSE AT THETA PRIME
-6600  C     C(17) IS WF = FWD PROP WEIGHT
-6600  C     C(18) IS ASF = FWD PROP AVERAGE SURFACE AREA
-6600  C     C(19) IS PFMX = FWD CHAMBER MAXIMUM PRESSURE
-6600  C     C(20) IS ASA = AFT PROP AVERAGE SURFACE AREA
-6600  C     C(21) IS BLANK
-6600  C     C(22) IS BLANK
-6600  C     C(23) IS BLANK
-6600  C     C(24) IS BLANK
-6600  C     C(25) IS BLANK
-6600  C     C(26) IS BLANK
-6600  C     C(27) IS ATA = AFT THROAT AREA
-6600  C     C(28) IS WEBF = FWD WEB THICKNESS
-6600  C     C(29) IS WEBA = AFT WEB THICKNESS
-6600  C     C(30) IS WA = AFT PROP WEIGHT
-6600  C     C(31) IS TBMX = MAXIMUM WEB TIME
-6600  C     C(32) IS PAMX = MAXIMUM AFT PRESSURE
-6600  C     C(33) IS CD = CDO
-6600  C     C(34) IS ATF = MAXIMUM OPERATING FWD THROAT AREA
-6600  C     C(35) IS BLANK
-6600        18 FORMAT (11HTHETA PRIME,F14.2)
-6652        19 FORMAT (11HAFT SURFACE,F14.2)
-6704        20 FORMAT (10HAFT THROAT,F16.3)
-6754        23 FORMAT (7HAFT WEB,F18.2)
-6798        24 FORMAT (13HAFT PROP. WT.,F12.2)
-6854        25 FORMAT (11HFWD SURFACE,F14.2)
-6906        26 FORMAT (7HFWD WEB,F18.2)
-6950        27 FORMAT (13HFWD PROP. WT.,F12.2)
-7006        28 FORMAT (12HMAX WEB TIME,F13.2)
-7060        51 FORMAT (7HFWD WEB,F18.2)
-7104       103 FORMAT (30H                              ,F20.6,15)
-7198        30 FORMAT(/36H P FWD      P AFT       THETA      THRUST)
-7300        31 FORMAT (/)
-7322        35 FORMAT (/13HPA GREATER PF)
-7378        43 FORMAT( F9.1,F9.1,F9.2,F9.1,F9.2,F9.0,F9.2,F9.4)
-7436        52 FORMAT(36X,36H  WT AFT    IMPULSE WEB AFT    AT FWD )
-7540       101 FORMAT( I4)
-7562       102 FORMAT( 3F20.10)
```

```
-7594   C
-7594   C      SWITCH 1 OFF TO PUNCH C(1) THRU C(35)
-7594   C      SWITCH 2 ON TO ACCEPT INPUT CHANGES ANYWHERE IN C(1) THRU C(35)
-7594   C      SWITCH 3 ON STOPS ALL OUTPUT PRINTING EXCEPT SUMMARY LINE
-7594   C
-7594          DIMENSION THE(30),XISP(30),CD(30),C(35)
-7594      502 PRINT 21
-7605          READ 102
-7613          PRINT 103
-7630          PUNCH 103
-7642          KK=1
-7654          IF(SENSE SWITCH 2)512,510
-7674      510 PRINT 31
-7686          READ 101,N
-7710          DO 499 K=1,N
-7722      499 READ 102,THE(K),XISP(K),CD(K)
-7873          DO 501 J=1,35
-7890          READ 103,C(J)
-7922          IF(C(J))550,501,550
-8013      550 PRINT 103,C(J)
-8065      501 CONTINUE
-8102          GO TO 520
-8110      512 READ 103,X,NP
-8146          IF(X)511,520,511
-8202      511 PRINT 103,X, NP
-8239          C(NP)=X
-8274          GO TO 512
-8282      520 PRINT 31
-8294          S4=C(13)
-8306          S5=C(14)
-8318          S6=C(15)
-8330          NF=0
-8342          LL=C(1)
-8378          F1=C(11)
-8390          P1=C(13)
-8402          GO TO(10,11,21),LL
-8482   C      10=OPTION IA
-8482   C      11=OPTION IB
-8482   C      21=OPTION II
-8482       10 C(20)=C(14)*C(3)*C(18)*C(4)*C(13)**C(5)/(C(6)*C(7)*C(15)**C(8))
-8586          GO TO 12
-8594       11 C(14)=C(6)*C(20)*C(7)*C(15)**C(8)/(C(3)*C(18)*C(4)*C(13)**C(5))
-8898       12 M=1
-8910       13 THEI=C(14)
-8922          K=1
-8934       14 IF(THE(K+1)-THEI)15,16,16
-9026       15 K=K+1
-9062          GO TO 14
-9070       16 RATIO=(THEI-THE(K))/(THE(K+1)-THE(K))
-9226          XISPO=XISP(K)+RATIO*(XISP(K+1)-XISP(K))
-9358          C(33)=CD(K)+RATIO*(CD(K+1)-CD(K))
-9490          GO TO(17,22,32),M
-9570       17 C(27)=(1.+C(14))*(C(3)*C(18)*C(4)*C(13)**C(5))/(C(33)*C(15))
-9762          PRINT 18,C(14)
-9786          PRINT 19,C(20)
-9810          PRINT 20,C(27)
-9834          C(28)=C(17)/(C(3)*C(18))
```

```
-9832          PRINT 51,C(28)
-9906          GO TO 29
-9914       21 M=2
-9926          GO TO 13
-9934       22 C(17)=C(16)/(XISPO*(1.+C(14)))
-9994          C(30)=C(17)*C(14)
J0030          C(31)=C(16)/C(11)
J0066          C(28)=C(31)*(C(4)*C(13)**C(5))
J0126          C(29)=C(31)*(C(7)*C(15)**C(8))
J0136          C(18)=C(17)/(C(3)*C(28))
J0234          C(20)=C(30)/(C(6)*C(29))
J0282          C(27)=(1.+C(14))*C(3)*C(18)*C(4)*C(13)**C(5)/(C(33)*C(15))
J0450          PRINT 20,C(27)
J0474          PRINT 19,C(20)
J0498          PRINT 23,C(29)
J0522          PRINT 24,C(30)
J0546          PRINT 25,C(18)
J0570          PRINT 26,C(28)
J0594          PRINT 27,C(17)
J0618          PRINT 28,C(31)
J0642       29 PRINT 30
J0654          PRINT 52
J0666          PRINT 31
J0678       44 CON1=C(3)*C(18)*C(4)*C(13)**C(5)
J0774       32 CON3=C(6)*C(20)*C(7)*C(15)**C(8)
J0870          PACAL=(CON1+CON3)/(C(27)*C(33))
J0954          IF(PACAL-C(13))50,34,34
J1022       34 PRINT 35
J1034          GO TO 46
J1042       50 IF(PACAL-.998*C(15))49,36,48
J1134       48 IF(PACAL-1.002*C(15))36,36,49
J1226       49 C(15)=2.*PACAL-C(15)
J1274          GO TO 32
J1282       36 THECA=CON3/CON1
J1318          IF(THECA-.998*C(14))38,39,37
J1410       37 IF(THECA-1.002*C(14))39,39,38
J1502       38 C(  )=0.5*(C(14)+THECA)
J1550          M=3
J1562          GO T  13
J1570       39 F=XI  P0*(CON1*(1.+THECA))
J1630      507 C(30)=C(17)*THECA
J1666          C(34)=CON1/(C(9)*C(13))
J1714          C(29)=C(28)*C(7)*PACAL**C(8)/(C(4)*C(13)**C(5))
J1858          XI=C(17)*(1.+THECA)*XISPO
J1918          GO TO(509,508),KK
J1994      509 GO TO(40,40,41),LL
J2074    C     40=OPTION I
J2074    C     41=OPTION II
J2074       40 IF(C(13)-C(19))42,42,46
J2142       41 IF(F-C(12))42,42,46
J2210       42 IF(SENSE SWITCH 3)513,514
J2230      514 PRINT 43,C(13),PACAL,THECA,F,C(30),XI,C(29),C(34)
J2338      513 IF(NF)1001,1002,1001
J2394     1002 S1=C(29)
J2406          S2=C(30)
J2418          S3=C(34)
J2430          NF=1
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```
J2442    1001 F1=F
J2454         P1=PACAL
J2466         C(13)=C(13)+C(10)
J2502         GO TO 44
J2510      45 KK=2
J2522         C(32)=((C(12)-F1)/(F-F1))*(PACAL-P1)+P1
J2666         C(19)=(C(12)/XISPO)-C(6)*C(20)*C(7)*C(32)**C(8)
J2822         C(19)=(C(19)/(C(3)*C(18)*C(4)))**(1./C(5))
J2954         THECA=(C(6)*C(7)*C(20)*C(32)**C(8))/(C(3)*C(4)*C(18)*C(19)**C(5))
J3158         GO TO 507
J3166     508 PRINT 31
J3178         PRINT 43,C(19),C(32),THECA,C(12),C(30),XI,C(29),C(34)
J3286         C(29)=S1
J3298         C(30)=S2
J3310         C(34)=S3
J3322         C(13)=S4
J3334         C(14)=S5
J3346         C(15)=S6
J3358     506 PAUSE
J3370         IF(SENSE SWITCH 1)502,503
J3390     503 DO 504 J=1,35
J3402     504 PUNCH 102,C(J)
J3486         GO TO 502
J3494         END
PROCESSING COMPLETE
START
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```
-6600  C      GRAIN CONFIGURATION PROGRAM FOR CSR PARAMETRIC STUDY
-6600  C      DR ALLEY      M K OPPRECHT     AUG 64
-6600  C      REVISION BY W. OSTERHOUT
-6600  C      DECEMBER 10,1964
-6600  C      PDO FORTRAN PROGRAM
-6600  C
-6600  C      C(18) IS  FORWARD CHAMBER AVERAGE SURFACE,SQ IN        ASF
-6600  C      C(28) IS  FORWARD CHAMBER WEB THICKNESS,IN             WEBF
-6600  C      C(27) IS  AFT THROAT AREA, SQ IN                       ATA
-6600  C      C(20) IS  AFT AVERAGE SURFACE AREA,  SQ IN             ASA
-6600  C      C(29) IS  AFT WEB THICKNESS, IN                        WEBA
-6600  C
-6600       1 FORMAT(30H                              ,F20.6,I3)
-6694       2 FORMAT (F20.6)
-6716       3 FORMAT (/22H FWD GRAIN IS A CYL EB)
-6790       4 FORMAT(12H FWD PROP OD,F10.2)
-6844       5 FORMAT(13H FWD PROP LEN,F10.2)
-6900       6 FORMAT(13H FWD PROP L/D,F10.2)
-6956       7 FORMAT(/22H FWD GRAIN IS A SPH EB)
-7030       8 FORMAT(/22H FWD GRAIN IS A CYL CP)
-7104       9 FORMAT(18H FWD CHAM VOL LOAD,F10.4)
-7170      10 FORMAT(/22H FWD GRAIN IS A SPH CP)
-7244      11 FORMAT(/24H FWD GRAIN IS A CYL STAR)
-7322      12 FORMAT(/24H FWD GRAIN IS A SPH STAR)
-7400      13 FORMAT(/22H FWD GRAIN IS A CYL WW)
-7474     102 FORMAT(/19H AFT GRAIN IS AN EB)
-7542     103 FORMAT(14H AFT GRAIN DIA,F10.3)
-7600     104 FORMAT(14H AFT GRAIN LEN,F10.3)
-7658     105 FORMAT(19H AFT GRAIN VOL LOAD,F10.3)
-7726     106 FORMAT(15H AFT GRAIN PORT,F10.3)
-7786     107 FORMAT(/18H AFT GRAIN IS A CP)
-7852     108 FORMAT(25H AFT PORT TO THROAT RATIO,F10.3)
-7932     109 FORMAT(/20H AFT GRAIN IS A STAR)
-8002     110 FORMAT(/18H AFT GRAIN IS A WW)
-8068     111 FORMAT(/39H AFT GRAIN IS AN EB OUTSIDE OF FWD CHAM)
-8176     112 FORMAT(/38H AFT GRAIN IS A CP OUTSIDE OF FWD CHAM)
-8292     500 FORMAT (30H                              )
-8366         DIMENSION  C(37)
-8366   C     FORWARD CHAMBER CALCULATIONS OR PYROGEN CALCULATIONS
-8366    1002 READ 500,N
-8390         PUNCH 500,N
-8414         PRINT 500,N
-8438         CONTROL 102
-8450         DIAA=0.
-8462         XLODA=0.
-8474         CONTROL 102
-8486         DO 501 J=1,37
-8498     501 C(J)=0.
-8570         DO 21 K=1,35
-8582      21 READ 2,C(K)
-8666         J=1
-8678         L=1
-8690         DIAF=(C(18)/.7854)**.5
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-8738          XLF=C(28)
-8750          XLODF=XLF/DIAF
-8786          IF(XLODF-.5)23,22,22
-8854       22 PRINT3
-8866          C(37)=2.
-8878          PRINT4,DIAF
-8902          PRINT5,XLF
-8926          PRINT6,XLODF
-8950          GO TO 45
-8953       23 IF(XLODF-.2)25,24,24
-9026       24 DIAF=((C(18)*C(28))/.4189 )**(1./3.)
-9146          VLF=.8
-9170          PRINT7
-9182          C(37)=3.
-9194       42 PRINT4,DIAF
-9218          PRINT9,VLF
-9242          XLODF=1.
-9254          GO TO 45
-9262       25 DIAF=C(28)/.35
-9298          M=1
-9310       26 DIAFS=DIAF*DIAF
-9346          VLF=(DIAFS-(DIAF-(2.*C(28)))**2.)/DIAFS
-9454          XLF=C(18)*C(28)/(.7854*VLF*DIAFS)
-9550          XLODF=XLF/DIAF
-9586          IF(XLODF-3.)29,27,27
-9654       27 GO TO (28,31),M
-9730       28 DIAF=C(28)/.3
-9766          M=2
-9778          GO TO 26
-9786       29 PRINT8
-9798          C(37)=1.
-9810          J=2
-9822       72 PRINT4,DIAF
-9846          PRINT5,XLF
-9870          PRINT6,XLODF
-9894          PRINT9,VLF
-9918          GO TO 45
-9926       31 DIAF=C(28)/.25
-9962          M=1
-9974          VLF=.85
-9998       32 XLF=(C(18)*C(28))/(.7854*VLF*DIAF*DIAF)
J0106          XLODF=XLF/DIAF
J0142          IF(XLODF-3.)35,33,33
J0210       33 GO TO (34,37),M
J0286       34 M=2
J0298          DIAF=C(28)/.2
J0334          VLF=.8
J0358          GO TO 32
J0366       35 PRINT11
J0378          C(37)=1.
J0390          J=3
J0402          GO TO 72
J0410       37 DIAF=C(28)/.15
J0446       38 XLF=C(18)*C(28)/(.7854*VLF*DIAF*DIAF)
J0554          XLODF=XLF/DIAF
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J0590          IF(XLODF-3.)40,41,41
J0653       40 PRINT13
J0670          C(37)=1.
J0682          GO TO 72
J0690       41 GO TO (45,42,40),M
J0770       42 DIAF=C(28)/.1
J0806          M=3
J0818          VLF=.7
J0842          GO TO 38
J0850 C        AFT GRAIN DESIGN IF C(2)=1.
J0850       45 IF(C(2))51,73,51
J0906       73 GO TO (81,20),L
J0932           81 GO TO (20,502,502),J
J1062      502 DIAF=(C(18)*C(28)/.4189)**(1./3.)
J1182          VLF=.8
J1206          GO TO (20,74,77),J
J1286       74 IF(C(28)-.3*DIAF)75,75,20
J1378       75 PRINT 10
J1390          C(37)=1.
J1402       76 PRINT 4,DIAF
J1426          PRINT 9,VLF
J1450          XLODF=1.
J1462          L=2
J1474          IF(C(2))80,20,80
J1530       77 IF(C(28)-.2*DIAF)78,20,20
J1622       78 PRINT12
J1634          C(37)=1.
J1646          XLODF=1.
J1658          GO TO 76
J1666       51 CONTROL 102
J1678          CONTROL 102
J1690       80 IF(XLODF-3.)65,65,63
J1758       65 DIAA=((C(20)+2.*C(27))/.786)**.5
J1830          XLODA=C(29)/DIAA
J1866          IF(XLODA-.5)55,53,53
J1934       53 XLA=C(29)
J1946          APA=2.*C(27)
J1982          VLA=1.-APA/(DIAA*DIAA*.786)
J2066          PRINT102
J2078          C(36)=2.
J2090       54 PRINT103,DIAA
J2114          PRINT104,XLA
J2138          PRINT105,VLA
J2162          PRINT106,APA
J2186          GO TO 73
J2194       55 DIAA=DIAF
J2206          WFA=C(29)/DIAA
J2242          IF(WFA-.3)60,56,56
J2310       56 IF(WFA-.4)90,59,59
J2378       90 APA=(DIAA-2.*C(29))**2.*.786
J2462          IF(APA-2.*C(27))59,57,57
J2554       57 VLA=1.-APA/(DIAA*DIAA*.786)
J2638          XLA=C(29)*C(20)/(.786*DIAA*DIAA*VLA)
J2746          PTA=APA/C(27)
J2782          PRINT107
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J2794            C(36)=1.
J2805         53 PRINT103,DIAA
J2830            PRINT104,XLA
J2854            PRINT105,VLA
J2878            PRINT108,PTA
J2902            GO TO 73
J2910         59 APA=2.*C(27)
J2946            DIAA=2.*C(29)+(APA/.786)**.5
J3042            VLA=1.-APA/(DIAA*DIAA*.786)
J3126            XLA=C(29)*C(20)/(.786*DIAA*DIAA*VLA)
J3234            PTA=2.0
J3246            PRINT107
J3258            C(36)=1.
J3270            GO TO 58
J3278         60 VLA=.85
J3302         69 APA=(1.-VLA)*DIAA*DIAA*.786
J3374            IF (APA-2.*C(27))70,71,71
J3466         70 VLA=VLA-.05
J3502            GO TO 69
J3510         71 XLA=C(20)*C(29)/(.786*DIAA*DIAA*VLA)
J3518            IF(VFA-.2)62,61,61
J3686         61 PRINT109
J3698            C(36)=1.
J3710            GO TO 54
J3718         62 PRINT110
J3730            C(36)=1.
J3742            GO TO 54
J3750         63 IF(C(29)-.6*XLF)64,66,66
J3842         64 IF(C(29)-.25*DIAF)68,65,65
J3934         66 APA=2.*C(27)
J3970            DIAA=.2+((C(20)+APA+.786*DIAF*DIAF)/.786)**.5
J4102            XLA=C(29)
J4114            VLA=C(20)/(C(20)+APA)
J4162            PRINT111
J4174            C(36)=3.
J4186            GO TO 54
J4194         68 APA=2.*C(27)
J4230            DIAA=2.*C(29)+((APA+0.786*(2.*C(29)+DIAF+.2)**2.)/.786)**.5
J4398            CONI=.786*DIAA*DIAA-.786*(DIAF+0.2)**2.-APA
J4542            VLA=CONI/(CONI+APA)
J4590            XLA=C(29)*C(20)/CONI
J4638            PRINT112
J4650            C(36)=4.
J4662            GO TO 54
J4670      C     PUNCH OUTPUT UNLESS SENSE SWITCH 1 IS ON
J4670         20 IF(SENSE SWITCH 1)1002,1003
J4690       1003 C(22)=DIAF
J4702            C(23)=DIAA
J4714            C(24)=XLODF
J4726            C(25) = XLA/DIAA
J4762            C(26)=C(2)
J4774            DO 1001 K=1,37
J4786       1001 PUNCH 1,C(K),K
J4882            PAUSE
J4894            GO TO 1002
J4902            END
PROCESSING COMPLETE
START
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-6600   C      CSR COMBINED WEIGHTS ANALYSIS PROGRAM
-6600   C       PROGRAM 5017A  24 NOV 64 M A TODD
-6600          DIMENSION C(70)
-6600          DO 250 J=1,70
-6612      250 C(J)=0
-6708       10 READ 200,X,I
-6744          PUNCH 200,X,I
-6780      201 READ 200,X,I
-6816          IF(X-9999999.)204,17,17
-6884      204 C(I)=X
-6920          GO TO 201
-6928       17 MCAG=C(36)
-6964          RHOF = C(3)
-6976          ALPF = C(4)
-6988          ENPF = C(5)
-7000          RHOA=C(6)
-7012          ALPA=C(7)
-7024          ENPA=C(8)
-7036          PAMN=C(15)
-7048          XIPR = C(16)
-7060          WF=C(17)
-7072          ASF = C(18)
-7084          PFMX=C(19)
-7096          ASA=C(20)
-7108          DIAF=C(22)
-7120          DIAA=C(23)
-7132          CHBNU = C(26)+1.
-7168          ATA=C(27)
-7180          WA=C(30)
-7192          TBMX=C(31)
-7204          PAMX=C(32)
-7216          ATF=C(34)
-7228          MCFG=C(37)
-7264          ROCHF=C(38)
-7276          ERATA=C(39)
-7288          SDCHA=C(40)
-7300          ROCHA=C(41)
-7312          ROINF=C(42)
-7324          ROINA=C(43)
-7336          CD=C(44)
-7348          WMIG=C(45)
-7360          GSIG=C(46)
-7372          FLTPI=C(47)
-7384          CPF=C(48)
-7396          THCOF=C(49)
-7408          WMFG=C(50)
-7420          TEMF=C(51)
-7432          CONIG=C(52)
-7444          XMFIG=C(53)
-7456          ENIG=C(54)
-7468          SFIG=C(55)
-7480          SDNTH=C(56)
-7492          SDNST=C(57)
-7504          SDNXN=C(58)
-7516          EXPRN=C(59)
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-7528          TEMA=C(50)
-7540          THCOA=C(52)
-7552          ERATF=C(53)
-7564          SDCHF=C(64)
-7576          PRCOH=C(65)
-7588          CPA=C(66)
-7600          WMAG =C(67)
-7612          IF(C(25)-1.)31,31,32
-7680       31 ELODA=0.
-7692          ERATA=1.0000001
-7704          GO TO 33
-7712       32 ELODA=C(25)-(ERATA-1.)/2.
-7784       33 IF(C(24)-1.)34,34,35
-7852       34 ELODF=0.
-7864          ERATF=1.0000001
-7876          GO TO 39
-7884       35 ELODF=C(24)-(ERATF-1.)/2.
-7956       39 RDCHF=DIAF/2.
-7992          RDCHA=DIAA/2.
-8028        4 RAD=(1.-(1./ERATA)**2.)**.5
-8112          WCX = ((RDCHA/ERATA)**2./2.*RAD)
-8184          IF(ERATA-2.5) 46,46,45
-8252       46 AFCL = (WCX*LOG((1.+RAD)/(1.-RAD))+RDCHA**2.)*3.14159
-8420          TFCL=(PAMX*RDCHA        )/(1.414*SDCHA*ROCHA)
-8516          GO TO 47
-8524       45 TFCL=RDCHA*((3.*PAMX)/4.*SDCHA*ROCHA)**.5
-8620          AFCL = 3.14159*(RDCHA)**2.
-8658       47 IF(TFCL-.025)43,44,44
-8736       43 TFCL=.025
-8760       44 WFCL=AFCL*TFCL*ROCHA
-8808          ACYL = 12.566*RDCHA*RDCHA*ELODA
-8868          TCYL=(PAMX*RDCHA/SDCHA*ROCHA)
-8928          IF(TCYL-.025)41,42,42
-8996       41 TCYL=.025
-9020       42 WCYL=ACYL*TCYL*ROCHA
-9068          WACL=(AFCL-2.*ATA)*TFCL*ROCHA
-9152          WCHBT=WFCL+WACL+WCYL
-9200          TINS=.007*TBMX*(((TEMA+460.)/5806.)**4.)+.05
-9320          WINFC=AFCL*TINS*ROINA
-9368          WINAC=(AFCL-2.*ATA)*TINS*ROINA
-9452          WINCY=ACYL*TINS*ROINA
-9500    C
-9500          IF(CHBNU-2.)209,8,8
-9568        8 F AD=(1.-(1./ERATF)**2.)**.5
-9652          WFCX=((RDCHF/ERATF)**2./2.*F AD)
-9724          IF(ERATF-2.5) 460,460,450
-9792      460 FAFCL=(WFCX*LOG((1.+F AD)/(1.-F AD))+RDCHF**2.)*3.14159
-9960          FTFCL=(PFMX*RDCHF        )/(1.414*SDCHF*ROCHF)
J0056          GO TO 470
J0064      450 FTFCL=RDCHF*((3.*PFMX)/4.*SDCHF*ROCHF)**.5
J0160          FAFCL = 3.14159*(RDCHF)**2.
J0208      470 IF(FTFCL-.025)430,440,440
J0276      430 FTFCL=.025
J0300      440 FWFCL=FAFCL*FTFCL*ROCHF
J0348          FACYL = 12.566*RDCHF*RDCHF*ELODF
```

```
J0408          FTCYL=(PFMX*RDCHF)/(SDCHF*ROCHF)
J0492          IF(FTCYL-.025)410,420,420
J0560      410 FTCYL=.025
J0584      420 FWCYL=FACYL*FTCYL*ROCHF
J0632          FWACL=(FAFCL-2.*ATF)*FTFCL*ROCHF
J0716          FCHBT=FWFCL+FWACL+FWCYL
J0764          FTINS=.007*TBMX*(((TEMF+460.)/5806.)**4.)+.05
J0834          FINFC=FAFCL*FTINS*ROINF
J0932          FINAC=(FAFCL-2.*ATF)*FTINS*ROINF
J1016          FINCY=FACYL*FTINS*ROINF
J1064     C
J1064          GO TO(210,211,212),MCFG
J1144     C    FWD GRAIN IS A CYL OR SPH  CP, STAR, WAGONWHEEL
J1144      210 FWINS=FINAC+FINFC
J1180          GO TO 209
J1188     C    FWD GRAIN IS A CYL END BURNER
J1188      211 FWINS=FINAC+(FINCY/2.)
J1236          GO TO 209
J1244     C    FWD GRAIN IS A SPH END BURNER
J1244      212 FWINS=FINAC+(FINFC/2.)
J1292     C
J1292      209 GO TO(205,206,207,208),MCAG
J1376     C    AFT GRAIN IS A CP,STAR,OR WAGONWHEEL
J1376      205 WINS=WINFC+WINAC
J1412          GO TO 100
J1420     C    AFT GRAIN IS AN END BURNER
J1420      206 WINS=WINAC+(WINCY/2.)
J1468          GO TO 100
J1476     C    AFT GRAIN IS AN END BURNER OUTSIDE OF FORWARD CHAMBER
J1476      207 WINS=WINFC+WINAC+(WINCY/2.)+FINAC+(FINCY/2.)
J1620          GO TO 100
J1628     C    AFT GRAIN IS A CP OUTSIDE OF FORWARD CHAMBER
J1628      208 WINS=WINFC+WINAC+FINAC+FINFC
J1688      100 WCASE=WCHBT+FCHBT
J1724          WINSL=WINS+FWINS
J1760          WIGT = 0.0
J1772          WIGP = 0.0
J1784          WIG = 0.0
J1796     C
J1796          PUNCH501,SDNST,SDNTH,SDNXN,SDCHA,SDCHF,XIPR
J1880          PUNCH 502,TEMA,TEMF,PAMX,PFMX,PAMN
J1952          PUNCH503,ELODA,ELODF,ERATA,ERATF,DIAA,DIAF
J2036          PUNCH 504,CHBNU,PRCON,WA,WF,TBMX,EXPRN
J2120          PUNCH 505,ATA,ATF,ASA,ASF,ROINA,ROINF
J2204          PUNCH 506,FLTPI,WMAG,WMFG,ALPA,ALPF
J2276          PUNCH 507,SFIG,WMIG,ENIG,GSIG,CONIG,XMFIG
J2360          PUNCH 508,ENPA,ENPF,CPA,CPF,THCOA,THCOF
J2444          PUNCH 509,WIGT,WIGP,WIG,RHOA,RHOF,CD
J2528          PUNCH 510,WINSL,WINFC,WINAC,WINCY,WINS,MCFG
J2612          PUNCH 511,FINFC,FINAC,FINCY,FWINS
J2672          PUNCH 512,WCASE,WFCL,WACL,WCYL,WCHBT,MCAG
J2756          PUNCH 513,FWFCL,FWACL,FWCYL,FCHBT
J2816          PUNCH 514,TCYL,TINS,FTCYL,FTINS,ROCHA,ROCHF
J2900      200 FORMAT(30H                              ,F20.6,I3)
J2994      501 FORMAT(4H 100,6F11.0)
```

```
J3056     502 FORMAT(4H 200,6F11.4)
J3118     503 FORMAT(4H 300,6F11.5)
J3180     504 FORMAT(4H 400,6F11.3)
J3242     505 FORMAT(4H 500,6F11.3)
J3304     506 FORMAT(4H 600,6F11.5)
J3366     507 FORMAT(4H 700,6F11.4)
J3428     508 FORMAT(4H 800,6F11.8)
J3490     509 FORMAT(4H 900,6F11.5)
J3552     510 FORMAT(4H1000,5F11.3,I11)
J3614     511 FORMAT(4H1100,6F11.3)
J3676     512 FORMAT(4H1200,5F11.3,I11)
J3738     513 FORMAT(4H1300,6F11.3)
J3800     514 FORMAT(4H1400,6F11.4)
J3862         GO TO 10
J3870         END
PROCESSING COMPLETE
START
```

```
-6600  C      CSR COMBINED WEIGHTS ANALYSIS PROGRAM
-6600  C       PROGRAM 5017B  27 OCT 64 M A TODD
-6600         DIMENSION C(31)
-6600      10 DO 250 J=1,31
-6612     250 C(J)=0
-6703         READ 200,X
-6732         PRINT 200,X
-6756         READ 501,SDNST,SDNTH,SDNXN,SDCHA,SDCHF,XIPR
-6840         READ  502,TEMA,TEMF,PAMX,PFMX,PAMN
-6912         READ 503,ELODA,ELODF,ERATA,ERATF,DIAA,DIAF
-6996         READ  504,CHBNU,PRCON,WA,WF,TBMX,EXPRN
-7080         READ  505,ATA,ATF,ASA,ASF,ROINA,ROINF
-7164         READ  506,FLTPI,WMAG,WMFG,ALPA,ALPF
-7236         READ  507,SFIG,WMIG,ENIG,GSIG,CONIG,XMFIG
-7320         READ  508,ENPA,ENPF,CPA,CPF,THCOA,THCOF
-7404         READ  509,WIGT,WIGP,WIG,RHOA,RHOF,CD
-7488         READ  510,WINSL,WINFC,WINAC,WINCY,WINS,MCFG
-7572         READ  511,FINFC,FINAC,FINCY,FWINS
-7632         READ  512,WCASE,WFCL,WACL,WCYL,WCHBT,MCAG
-7716         READ  513,FWFCL,FWACL,FWCYL,FCHBT
-7776         READ  514,TCYL,TINS,FTCYL,FTINS,ROCHA,ROCHF
-7860         RDCHA = DIAA/2.
-7896         RDCHF = DIAF/2.
-7932         IF(CHBNU-2.)7,19,19
-8000  C      VALVE WEIGHT CALCULATION
-8000  C      VFREE=C(1),DTHT=C(2),DTH2=C(3),DTH3=C(4),PLINS=C(5)
-8000  C      COVIN=C(6),TUBIN=C(7),PISIN=C(8),TOINS,C(9),PISTN=C(10)
-8000  C      PINT=C(11),COVE=C(12),PIST=C(13),CYL=C(14),DUCT=C(15)
-8000  C      STRUT=C(16),PLI[illegible]=C(17),POWPK=C(18),SERVO=C(19),VALVE=C(20)
-8000      19 C(1)=6.283*(RDCHF**2.)*(ELODF+2./(3.*ERATF))
-8120  5      C(2)=(ATF/.7856)**.5
-8168         C(3)=C(2)**2.
-8204         C(4)=C(2)**3.
-8240         IF(TBMX-9.)20,21,21
-8308      20 C(5)=.0225*C(3)
-8344         C(6)=.02097*C(3)
-8380         C(7)=.0476*C(3)
-8416         C(8)=.0146*C(3)
-8452         GO TO 22
-8460      21 C(5) =.0025*C(3)*TBMX
-8508         C(6) =.00233*C(3)*TBMX
-8556         C(7) =.0053*C(3)*TBMX
-8604         C(8) =.00162*C(3)*TBMX
-8652      22 C(9)=C(5)+C(6)+C(7)+C(8)
-8712         IF(C(2)-.68)23,24,24
-8780      23 C(10)=(.022*C(3))+(.0000294*C(3)*(PFMX**.5))
-8912         GO TO 25
-8920      24 C(10)=(.022*C(3))+(.0000581*C(4)*(PFMX**.5))
-9052      25 IF(C(2)-1.07)26,27,27
-9120      26 C(11)=.0302*C(3)
-9156         GO TO 28
-9164      27 C(11)=.0282*C(4)
-9200      28 IF(C(2)-2.38)29,30,30
-9268      29 C(12)=(.0934*C(3))+(.0575*C(4))
-9352         GO TO 31
```

```
-9360      30 C(12)=.0966*C(4)
-9396      31 IF(C(2)-2.67)32,33,33
-9464      32 C(13)=.0403*C(3)
-9500         GO TO 34
-9508      33 C(13)=(.022*C(3))+(.00676*C(4))
-9592      34 IF(C(2)-2.9)35,36,36
-9660      35 C(14)=(.00792*C(3))+(.027*C(4))
-9744         GO TO 37
-9752      36 C(14)=.0297*C(4)
-9788      37 IF(C(2)-1.07)38,39,39
-9856      38 C(15)=.0602*C(3)
-9892         GO TO 40
-9900      39 C(15)=.00563*C(4)
-9936      40 C(16)=(.000301*C(4)*(PFMX**.666))
J0020         C(17)=(.00939*C(4)*((PFMX-PAMX)**.5))
J0116         C(18)=.33*C(4)
J0152         C(19)=(.59*C(4))+.9
J0200         C(31)=C(9)+C(10)+C(11)+C(12)+C(13)+C(14)+C(15)+C(16)+C(17)
J0320         C(20)=C(31)+C(18)+C(19)
J0368         AS=ASF
J0380         RHO=RHOF
J0392         TEM=TEMF
J0404         ENP=ENPF
J0416         CP=CPF
J0428         ALP=ALPF
J0440         THCO=THCOF
J0452         WMG=WMFG
J0464         GO TO 100
J0472   C     IGNITER WEIGHT CALCULATION
J0472       7 PRINT 70
J0484         C(1)=6.283*(RDCHA**3.)*(ELODA+2./(3.*ERATA))
J0604         AS=ASA
J0616         RHO=RHOA
J0628         TEM=TEMA
J0640         ENP=ENPA
J0652         CP=CPA
J0664         ALP=ALPA
J0676         THCO=THCOA
J0688         WMG=WMAG
J0700     100 CON1=AS *RHO *TEM  *18550./(C(1) *WM G)
J0808         CON2=(CON1*2.*THCO *ENP )/(CP *ALP *RHO )
J0928         PSTAR = (CONIG*CON2)**(1./(1.+ENP))
J1048         WIGP=(WMIG*PSTAR*C(1) )/(GSIG*FLTPI*18550.)*SFIG
J1168         WIG=WIGP/XMFIG
J1204         WIGT=WIG*ENIG
J1240   C     NOZZLE WEIGHT CALCULATION
J1240   C     WNST=C(21),SDST=C(22),WNSTR=C(23),WNTH=C(24),SDTH=C(25)
J1240   C     WNTHT=C(26),WNXI=C(27),SDXN=C(28),WNXIN=C(29),WNOZ=C(30)
J1240         C(21)=((104.+(9.65*EXPRN))*(ATA)**1.5)*PAMX/1000000.
J1360         C(22)=773000./SDNST
J1396         C(23)=C(21)*C(22)
J1432         C(24)=1.53*ATA**.9
J1480         C(25)=128900./SDNTH
J1516         C(26)=C(24)*C(25)
J1552         C(27)=.00218*ATA*(EXPRN-4.)*TBMX*(1./CD)**1.7*PAMN**.8/1000000.
```

```
J1768          C(28)=40000./SDNXN
J1804          C(29)=C(27)*C(28)
J1840          C(30)=C(23)+C(26)+C(29)
J1888   C    COMPONENT LENGTH CALCULATION
J1888          FWDLT=2.*RDCHF*((ELODF*ERATF+1.)/ERATF)
J1936          AFTLT=2.*RDCHA*((ELODA*ERATA+1.)/ERATA)
J2104          XNOLT=((ATA/3.14159)**.5*((EXPRN)**.5-1.))/.3153
J2224   C    MOTOR WEIGHT, MASS FRACTION, AND DELTA VELOCITY CALCULATION
J2224          WCHB=WCASE+WINSL
J2260          WINRT =(WCHB+C(20)+WIGT+C(30))*1.02
J2332          WPROP=WA+WF
J2368          XMFRC=(WA+WF)/(WPROP+WINRT)
J2452          DELV=(32.174)*(XIPR/WPROP)*LOG ((WINRT+WPROP)/(WINRT))
J2572          WMTR=WINRT+WPROP
J2608   C      IF GRAIN CONFIG IS TANDEM ADD ALL LENGTHS.  IF GRAIN CONFIG IS
J2608   C      PARALLEL CHECK FOR LONGER OF FWD AND AFT CHAMBERS AND ADD NOZZLE
J2608          IF(MCAG-3)300,301,301
J2676      300 RLGT=FWDLT+AFTLT+XNOLT
J2724          GO TO 304
J2732      301 IF(FWDLT-AFTLT)302,302,303
J2800      302 RLGT=AFTLT+XNOLT
J2836          GO TO 304
J2844      303 RLGT=FWDLT+XNOLT
J2880      304 IF(RDCHF-RDCHA)305,305,306
J2948      305 RDIA=2.*RDCHA+2.*TCYL+2.*TINS
J3080          GO TO 307
J3088      306 RDIA=2.*(RDCHF+FTCYL+FTINS)
J3148      307 ELODM=RLGT/RDIA
J3184          IF(SENSE SWITCH 1)309,308
J3204      308 IF(SENSE SWITCH 2) 311,310
J3224      311 PRINT 511,C(1),CON1, PSTAR, FWDLT, AFTLT, XNOLT
J3308      310 PRINT501,SDNST,SDNTH,SDNXN,SDCHA,SDCHF,XIPR
J3392          PRINT 502,TEMA,TEMF,PAMX,PFMX,PAMN
J3464          PRINT503,ELODA,ELODF,ERATA,ERATF,DIAA,DIAF
J3548          PRINT 504,CHBNU,PRCON,WA,WF,TBMX,EXPRN
J3632          PRINT 505,ATA,ATF,ASA,ASF,ROINA,ROINF
J3716          PRINT 506,FLTPI,WMAG,WMFG,ALPA,ALPF
J3788          PRINT 507,SFIG,WMIG,ENIG,GSIG,CONIG,XMFIG
J3872          PRINT 508,ENPA,ENPF,CPA,CPF,THCOA,THCOF
J3956          PRINT 509,WIGT,WIGP,WIG,RHOA,RHOF,CD
J4040          PRINT 510,WINSL,WINFC,WINAC,WINCY,WINS,NCFG
J4124          PRINT 511,FINFC,FINAC,FINCY,FWINS
J4184          PRINT 512,WCASE,WFCL,WACL,WCYL,WCHBT,MCAG
J4268          PRINT 513,FWFCL,FWACL,FWCYL,FCHBT
J4328          PRINT 514,TCYL,TINS,FTCYL,FTINS,ROCHA,ROCHF
J4412          PRINT 515,C(20),C(9),C(10),C(13),C(11),C(12)
J4496          PRINT 516,C(19),C(18),C(17),C(16),C(15),C(14)
J4580          PRINT 517,C(30),C(23),C(26),C(29),EXPRN
J4652      309 PRINT 518,WMTR,RDIA,RLGT,XMFRC,DELV,ELODM
J4736          PUNCH 200,XMFRC,DELV,RLGT,RDIA
J4796       70 FORMAT (28HSINGLE CHAMBER MOTOR FOLLOWS)
J4876      200 FORMAT(30H                              ,F11.3,F11.0,2F11.2)
J4980      501 FORMAT(4H 100,6F11.0)
J5042      502 FORMAT(4H 200,6F11.4)
J5104      503 FORMAT(4H 300,6F11.5)
```

```
J5166     504 FORMAT(4H 400,6F11.3)
J5228     505 FORMAT(4H 500,6F11.3)
J5290     506 FORMAT(4H 600,6F11.5)
J5352     507 FORMAT(4H 700,6F11.4)
J5414     508 FORMAT(4H 800,6F11.8)
J5476     509 FORMAT(4H 900,6F11.5)
J5538     510 FORMAT(4H1000,5F11.3,111)
J5600     511 FORMAT(4H1100,6F11.3)
J5662     512 FORMAT(4H1200,5F11.3,111)
J5724     513 FORMAT(4H1300,6F11.3)
J5786     514 FORMAT(4H1400,6F11.4)
J5848     515 FORMAT(4H1500,6F11.4)
J5910     516 FORMAT(4H1600,6F11.4)
J5972     517 FORMAT(4H1700,6F11.4)
J6034     518 FORMAT(4H1800,6F11.4)
J6096         CONTROL 102
J6103         GO TO 10
J6116         END
PROCESSING COMPLETE
START
```

APPENDIX B - PRESENTATION OF DATA

A detailed presentation of data from this study is given herein in Figures B-1 through B-66. For ease of reference, the figures are presented by phase, and are arranged in sequence. Figures B-1 through B-30 present the results from Phase I; the remaining figures are for Phase II.

The plots for Phase I are presented in the following sequence:

- Mass fraction versus minimum thrust at an I_{sp} of 265 lb_f-sec/lb_m for 1, 10, and 20 starts (Figures B-1, B-2, and B-3, respectively); at an I_{sp} of 280 lb_f-sec/lb_m for 1, 10, and 20 starts (Figures B-4, B-5, and B-6, respectively); and at an I_{sp} of 300 lb_f-sec/lb_m for 1, 10, and 20 starts (Figures B-7, B-8, and B-9). For each plot, curves are shown for total impulse values of 10^4, 10^5, and 10^6 lb_f-sec at constant thrust ratios of 1, 5, and 20.

- Mass fraction versus total impulse for burn times of 20, 50, 200, and 500 sec (Figures B-10 through B-13, respectively). All curves are for 10 starts and constant specific impulse of 280 lb_f-sec/lb_m.

- Delta velocity versus minimum thrust at an I_{sp} of 265 lb_f-sec/lb_m for 1, 10, and 20 starts (Figures B-14, B-15, and B-16, respectively); at an I_{sp} of 280 lb_f-sec/lb_m for 1, 10, and 20 starts (Figures B-17, B-18, and B-19, respectively); and at an I_{sp} of 300 lb_f-sec/lb_m for 1, 10, and 20 starts (Figures B-20, B-21, and B-22, respectively). For each plot, curves are shown for total impulse values of 10^4, 10^5, and 10^6 lb_f-sec at constant thrust ratios of 1, 5, and 20.

- Delta velocity versus total impulse for burn times of 20, 50, 200, and 500 sec (Figures B-23 through B-26, respectively). All curves are for 10 starts and constant specific impulse of 280 lb_f-sec/lb_m.

- Length versus minimum thrust for I_{sp} of 265 and 300 lb_f-sec/lb_m (Figures B-27 and B-28, respectively). Curves of constant configuration are shown on each plot.

- Diameter versus minimum thrust for I_{sp} of 265 and 300 lb_f-sec/lb_m (Figures B-29 and B-30, respectively). Curves of constant configuration and constant total impulse values (10^4, 10^5, 5×10^5, and 10^6 lb_f-sec) are shown on each plot.

(Confidential)

The plots for Phase II are arranged as follows:

- Mass fraction versus minimum thrust at thrust ratios of 1, 5, and 20 (Figures B-31, B-32, and B-33, respectively). Curves for three materials are shown on each plot.

- Delta velocity versus minimum thrust at thrust ratios of 1, 5, and 20 (Figures B-34, B-35, and B-36, respectively). Curves for three materials are shown on each plot.

- Mass fraction versus minimum thrust for aft propellant burning-rate constants of 0.0002, 0.0004, and 0.0010 (Figures B-37, B-38, and B-39, respectively). Curves for constant forward propellant burning rates of 0.002, 0.0008, and 0.0032 are shown on each plot.

- Delta velocity versus minimum thrust for aft propellant burning-rate constants of 0.0002, 0.0004, and 0.0010 (Figures B-40, B-41, and B-42, respectively). Curves for constant forward propellant burning rates of 0.0002, 0.0008, and 0.0032 are shown on each plot.

- Length versus aft propellant burning-rate constant at minimum thrust values of 200, 500, 1000, and 5000 lb_f (Figures B-43 through B-46, respectively). Curves for constant forward propellant burning rates of 0.0002, 0.0008, and 0.0032 are shown on each plot.

- Diameter versus aft propellant burning-rate constant at minimum thrust values of 200, 500, 1000, and 5000 lb_f (Figures B-47, through B-50, respectively). Curves for constant forward propellant burning rates of 0.0002, 0.0008, and 0.0032 are shown on each plot.

- Mass fraction versus thrust ratio at forward propellant burning-rate exponents of 0.6 0.8, and 0.9 (Figures B-51, B-52, and B-53, respectively). Curves for constant aft propellant burning rate exponents of 0.8, 1.0, and 1.1 are shown on each plot.

- Delta velocity versus thrust ratio at forward propellant burning-rate exponents of 0.6, 0.8, and 0.9 (Figures B-54, B-55, and B-56, respectively). Curves for constant aft propellant burning-rate exponents of 0.8, 1.0, and 1.1 are shown on each plot.

- Length versus thrust ratio at forward propellant burning-rate exponents of 0.6, 0.8, and 0.9 (Figures B-57, B-58, and B-59, respectively). Curves for constant aft propellant burning-rate exponents of 0.8, 1.0, and 1.1 are shown on each plot.

- Diameter versus thrust ratio at forward propellant burning-rate exponents of 0.6, 0.8, and 0.9 (Figures B-60, B-61, and B-62, respectively). Curves for constant aft propellant burning-rate exponents of 0.8, 1.0, and 1.1 are shown on each plot.

- Mass fraction versus minimum thrust (Figure B-63). Curves for constant theta values of 2, 3, and 4 are shown.

- Delta velocity versus minimum thrust (Figure B-64). Curves for constant theta values of 2, 3, and 4 are shown.

- Length versus minimum thrust (Figure B-65). Curves for constant theta values of 2, 3, and 4 are shown.

- Diameter versus minimum thrust (Figure B-66). Curves for constant theta values of 2, 3, and 4 are shown.

(Confidential)

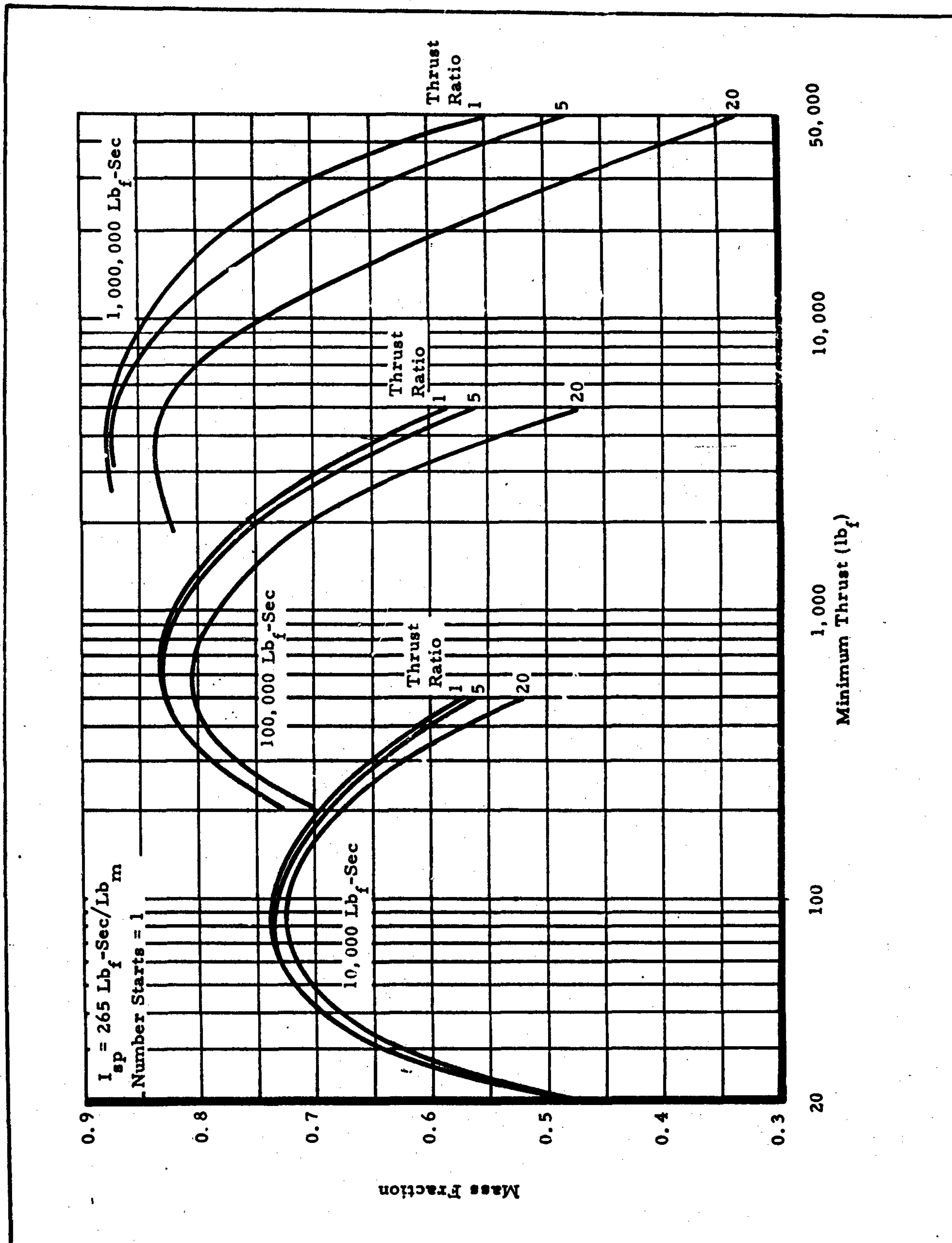

Figure B-1 - Mass Fraction versus Minimum Thrust for I_{sp} = 265 Lb_f-Sec/Lb_m and 1 Start

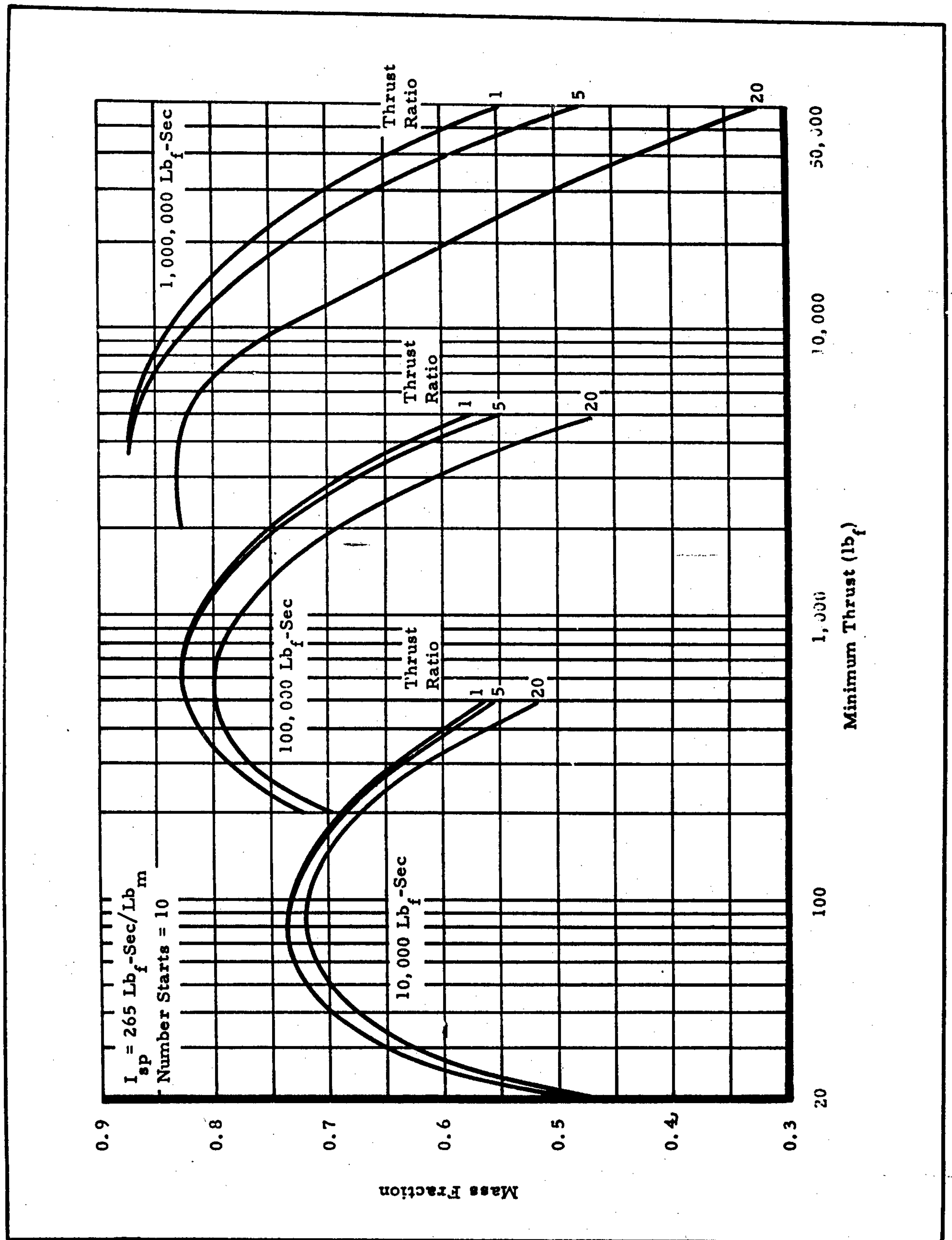

Figure B-2 - Mass Fraction versus Minimum Thrust for I_{sp} = 265 Lb$_f$-Sec/Lb$_m$ and 10 Starts

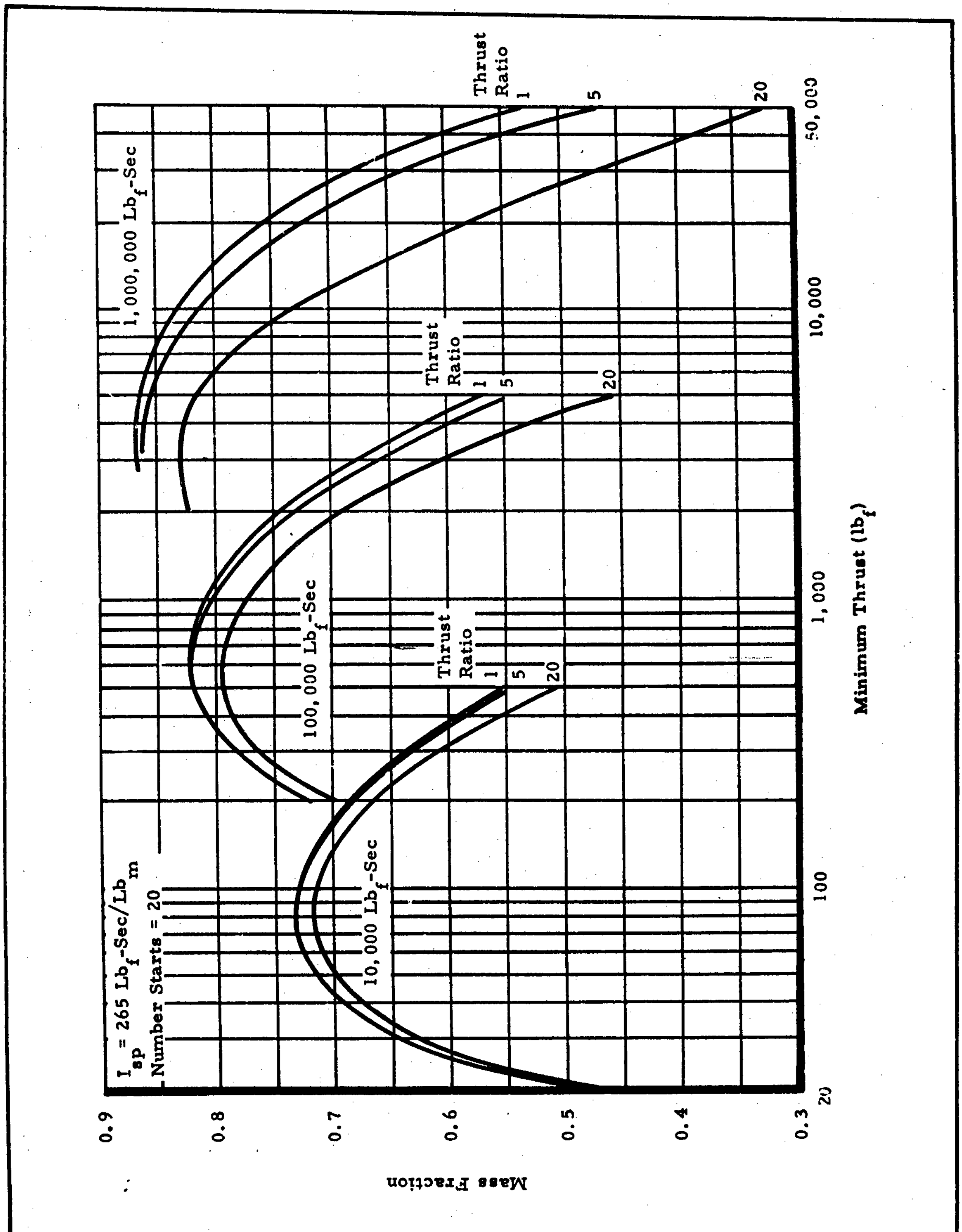

Figure B-3 - Mass Fraction versus Minimum Thrust for I_{sp} = 265 Lb_f-Sec/Lb_m and 20 Starts

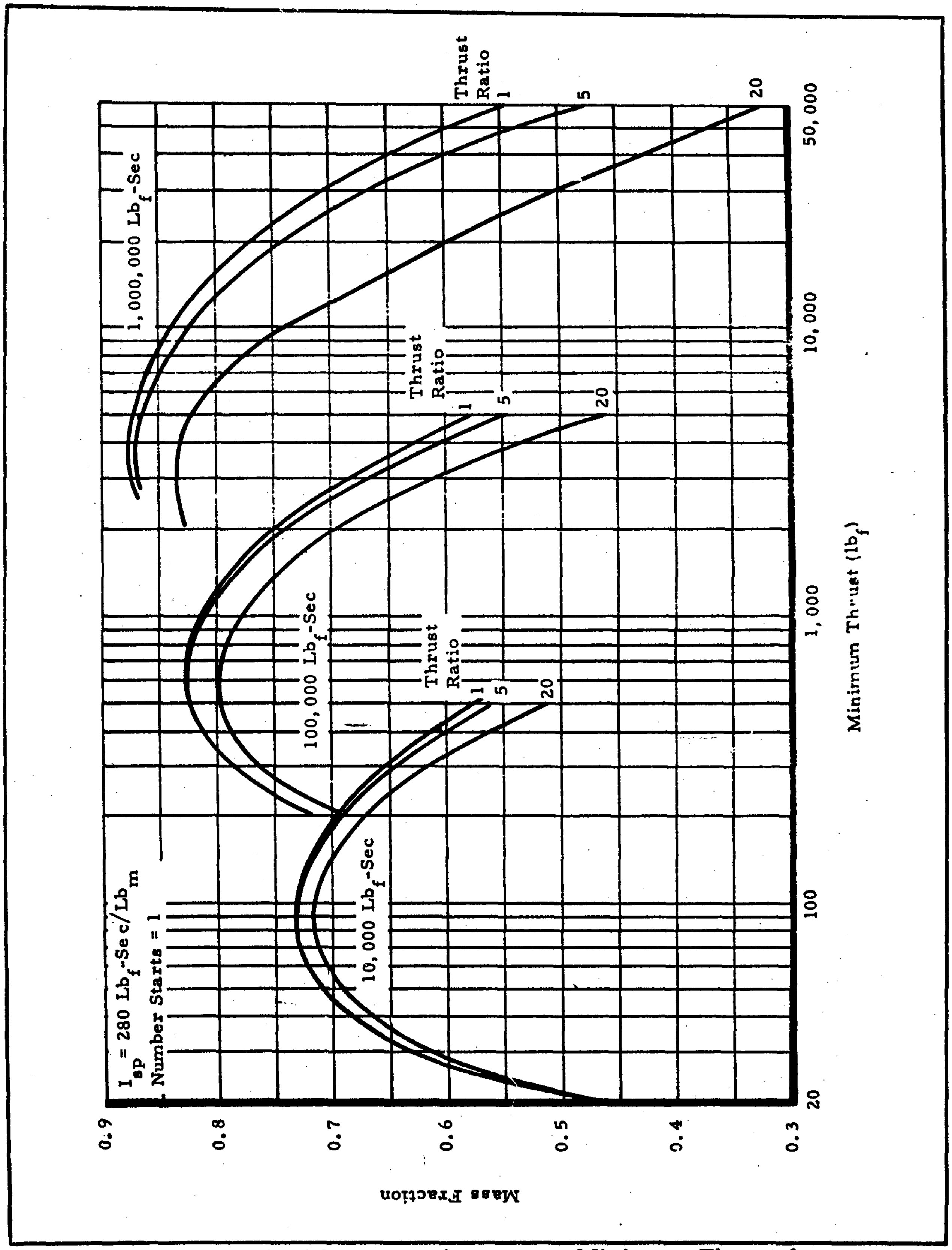

Figure B-4 - Mass Fraction versus Minimum Thrust for I_{sp} = 280 Lb_f-Sec/Lb_m and 1 Start

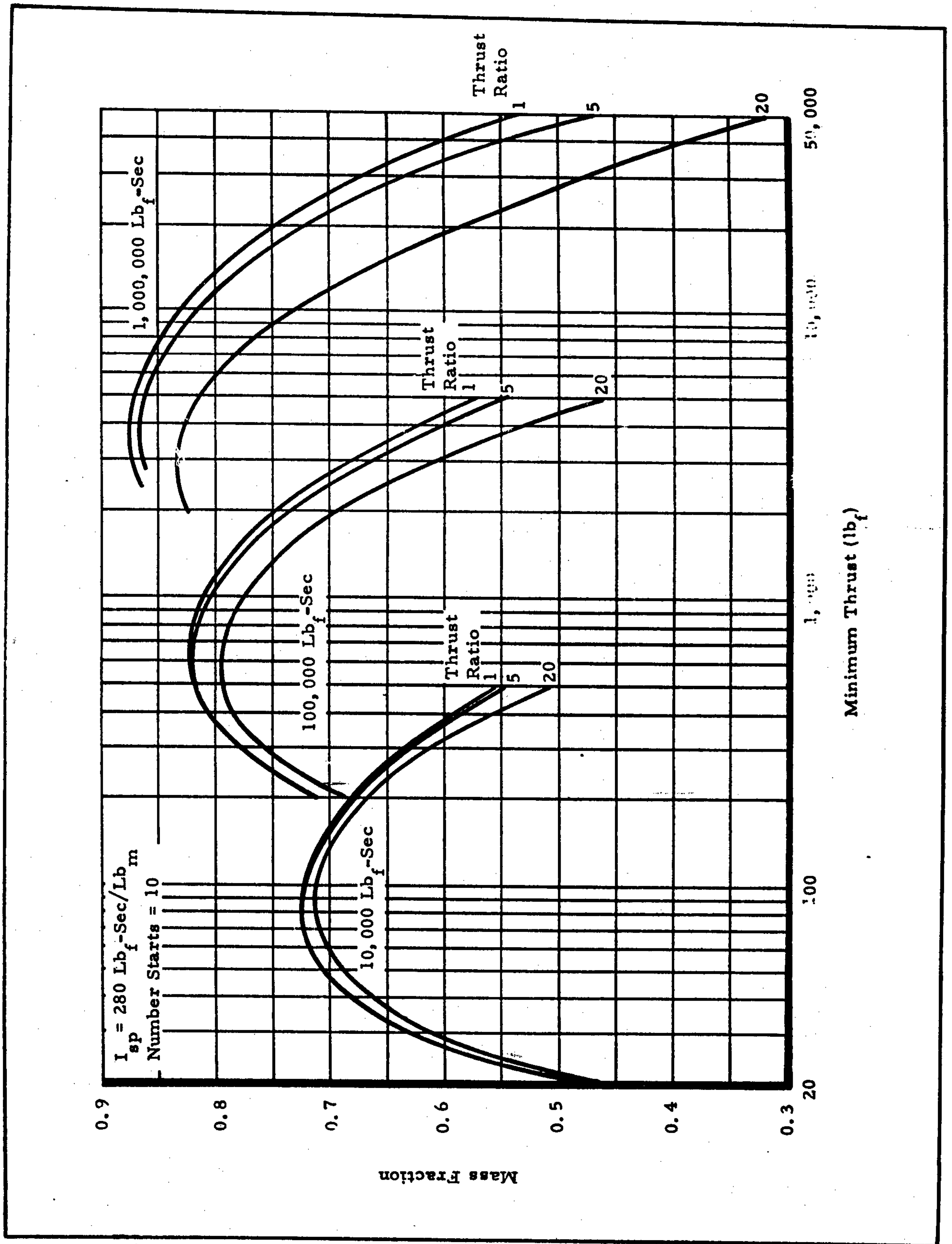

Figure B-5 - Mass Fraction versus Minimum Thrust for I_{sp} = 280 Lb_f-Sec/Lb_m and 10 Starts

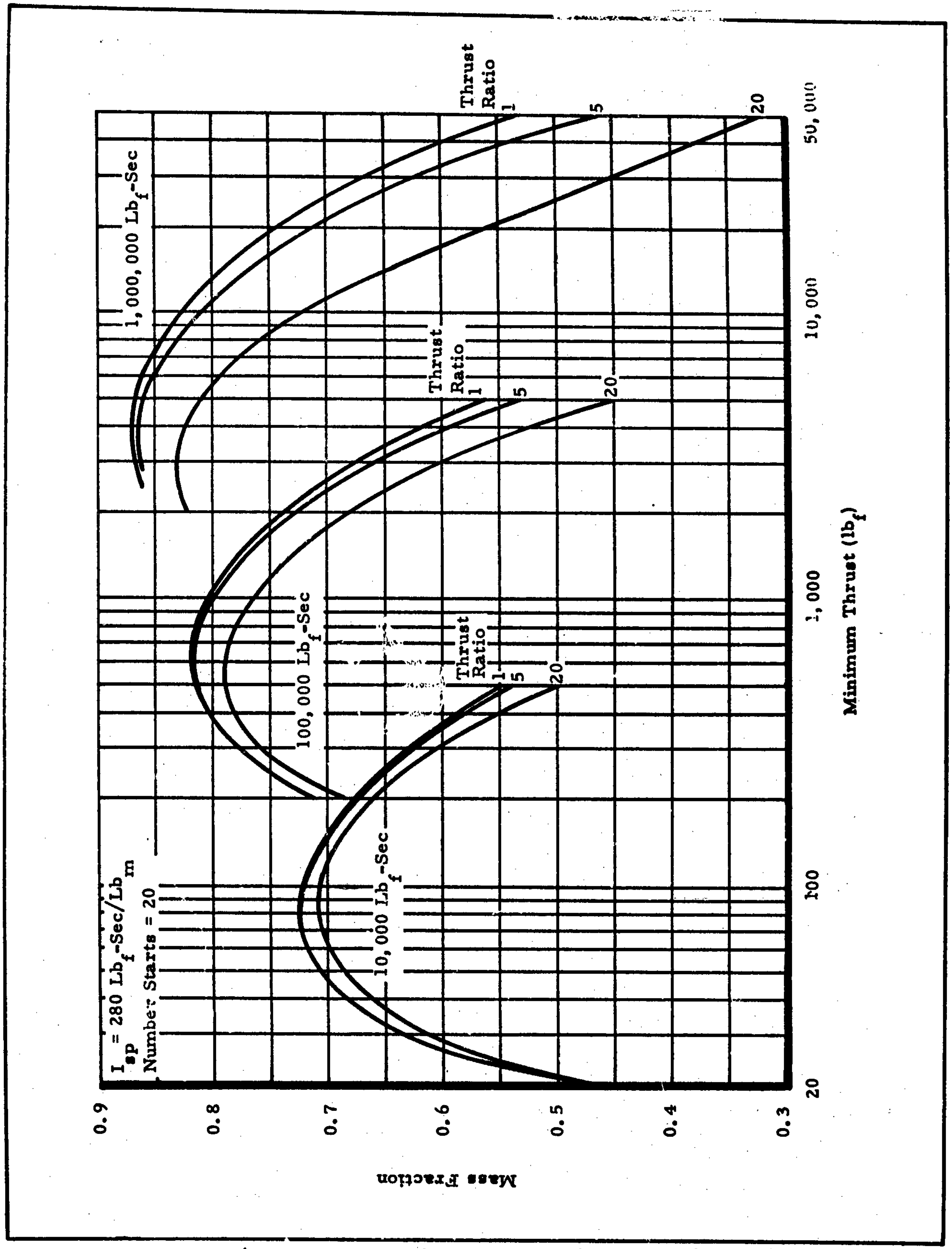

Figure B-6 - Mass Fraction versus Minimum Thrust for I_{sp} = 280 Lb_f-Sec/Lb_m and 20 Starts

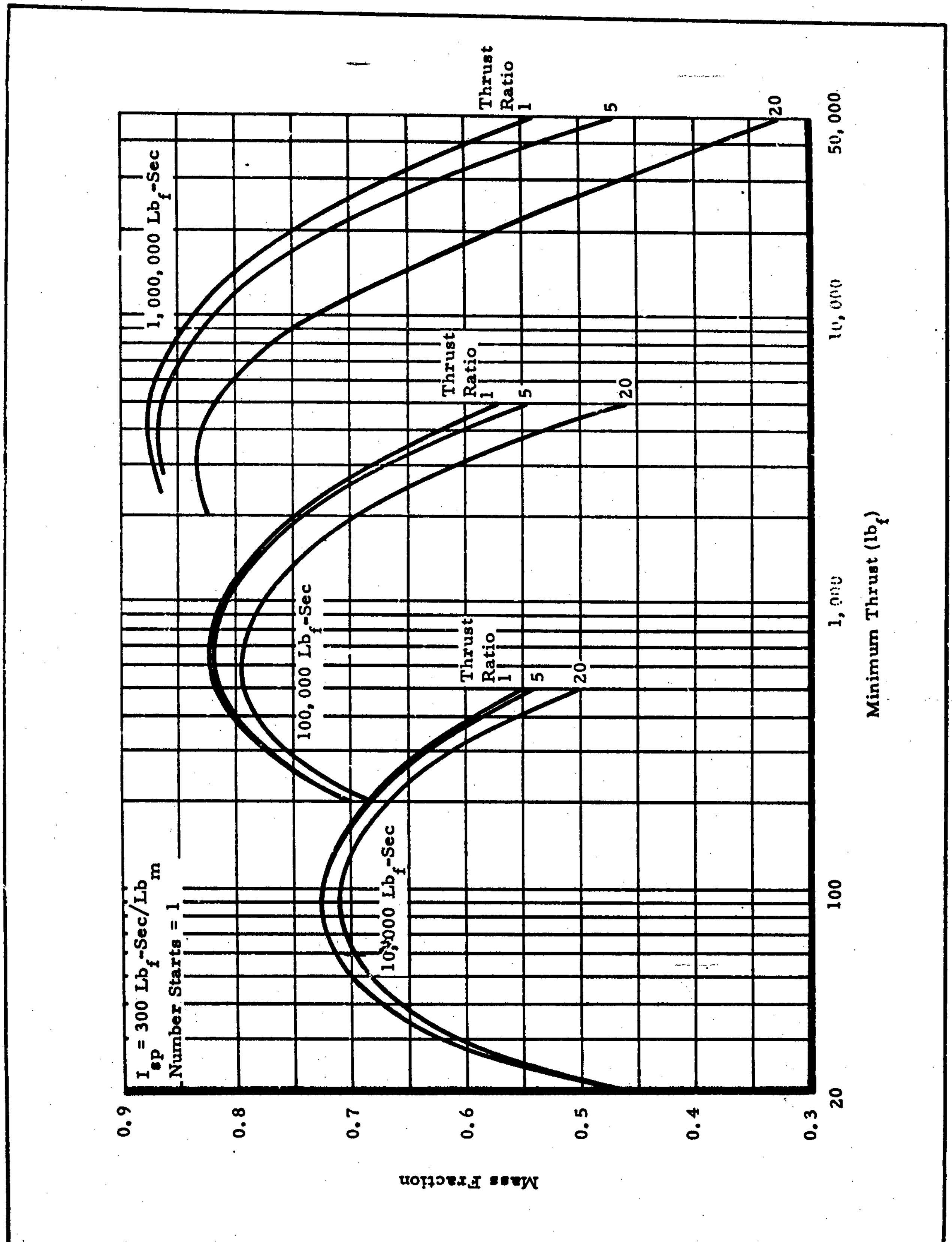

Figure B-7 - Mass Fraction versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m and 1 Start

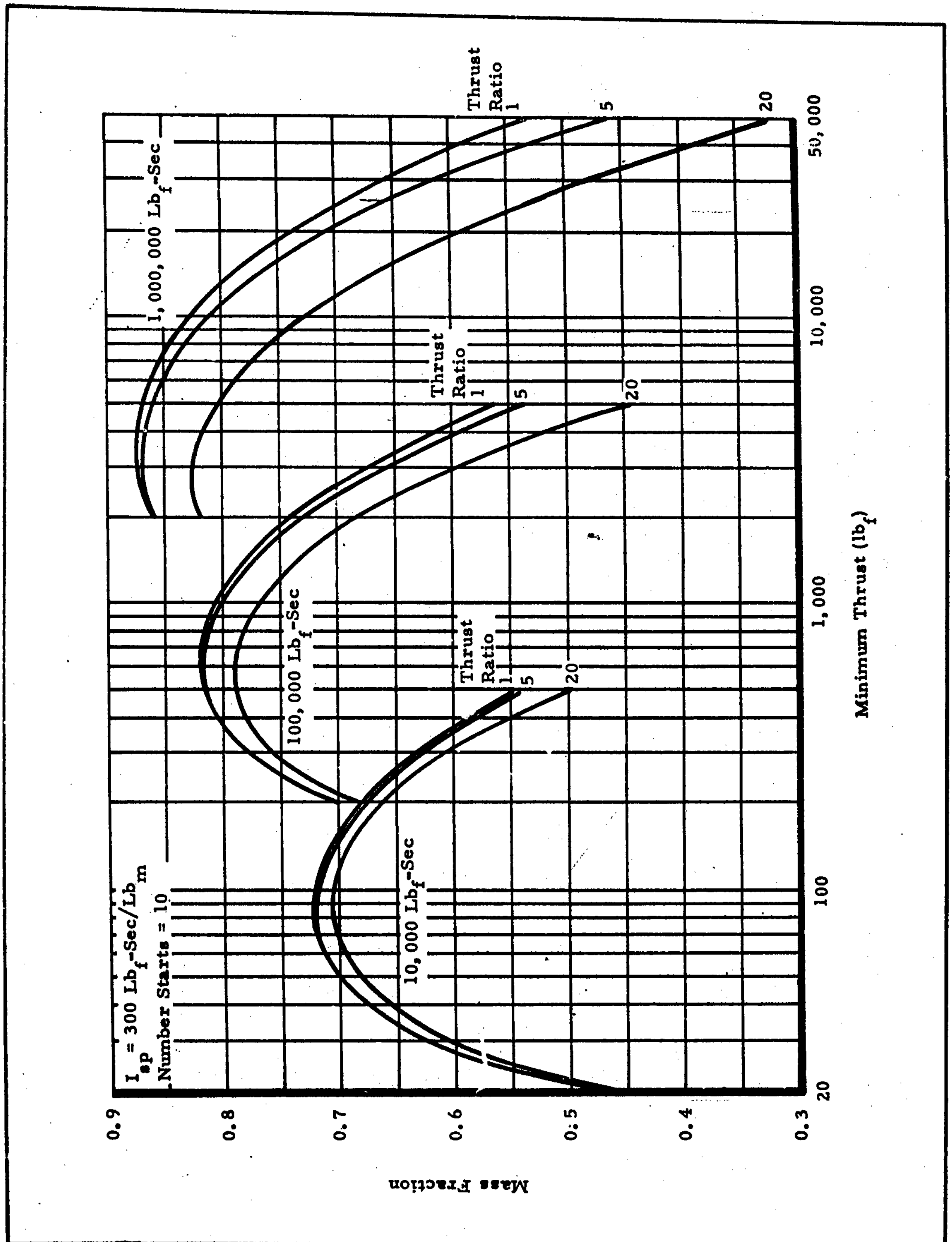

Figure B-8 - Mass Fraction versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m and 10 Starts

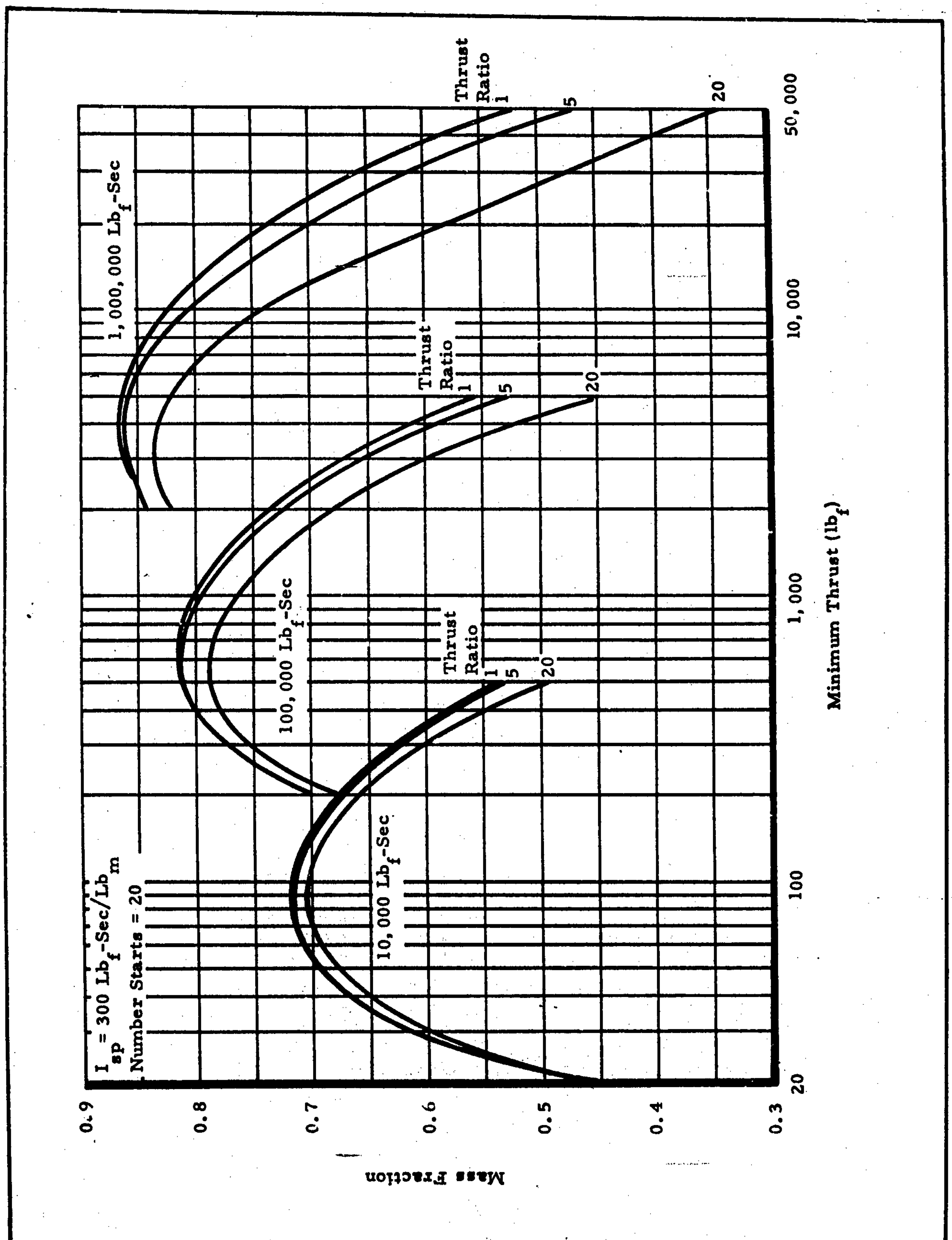

Figure B-9 - Mass Fraction versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m and 20 Starts

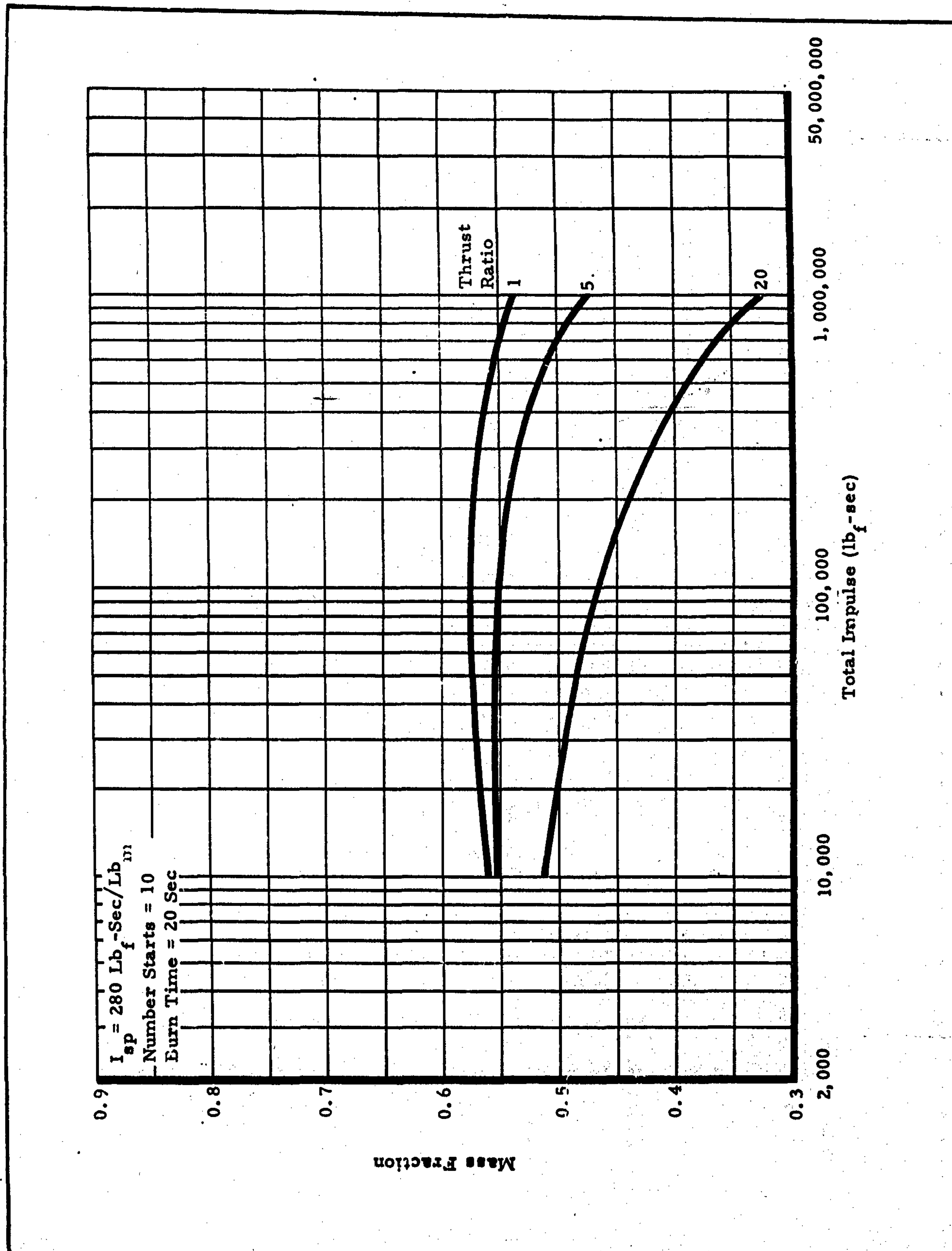

Figure B-10 - Mass Fraction ve-sus Total Impulse for 20-Sec Burn Time

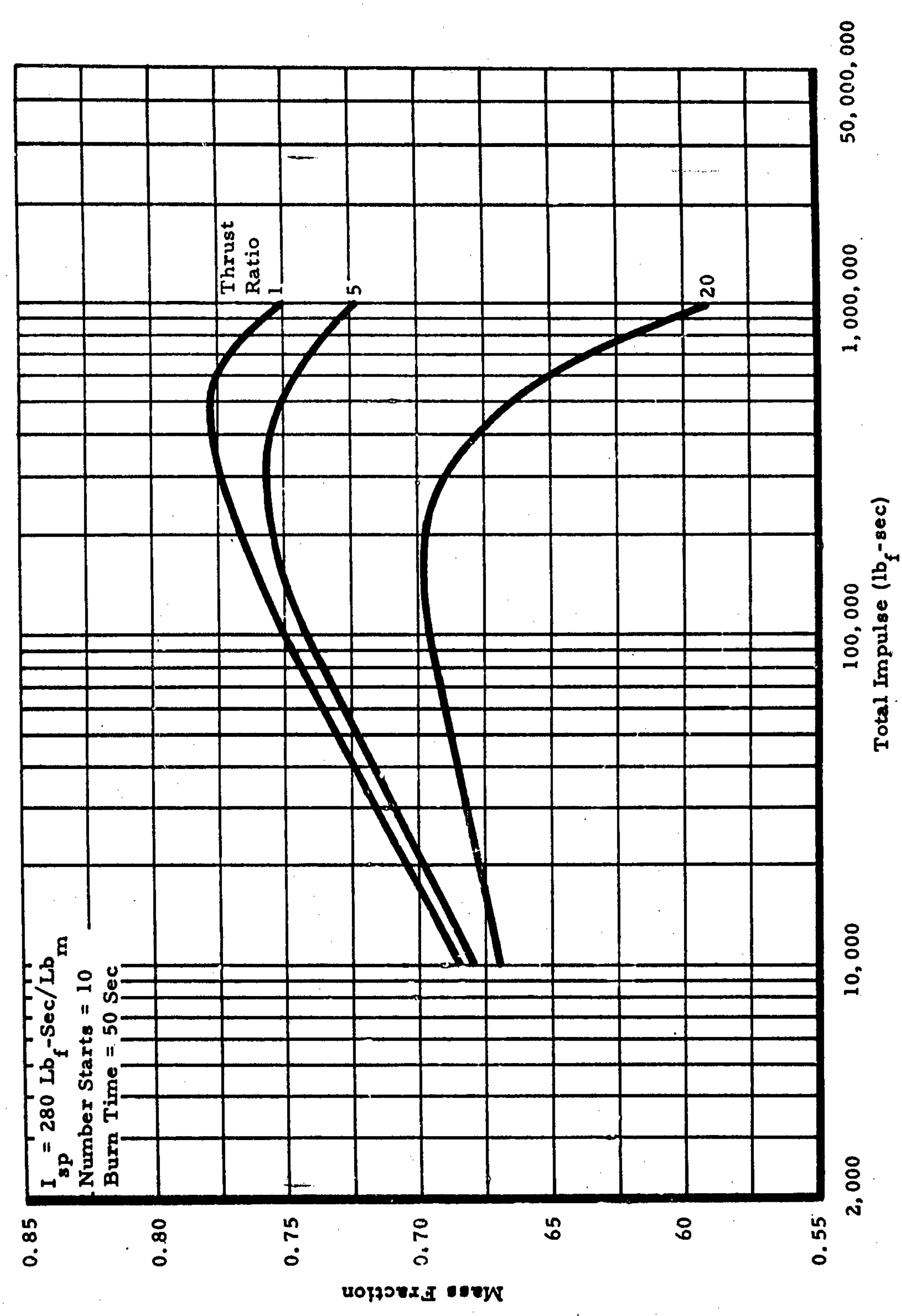

Figure B-11 - Mass Fraction versus Total Impulse for 50-Sec Burn Time

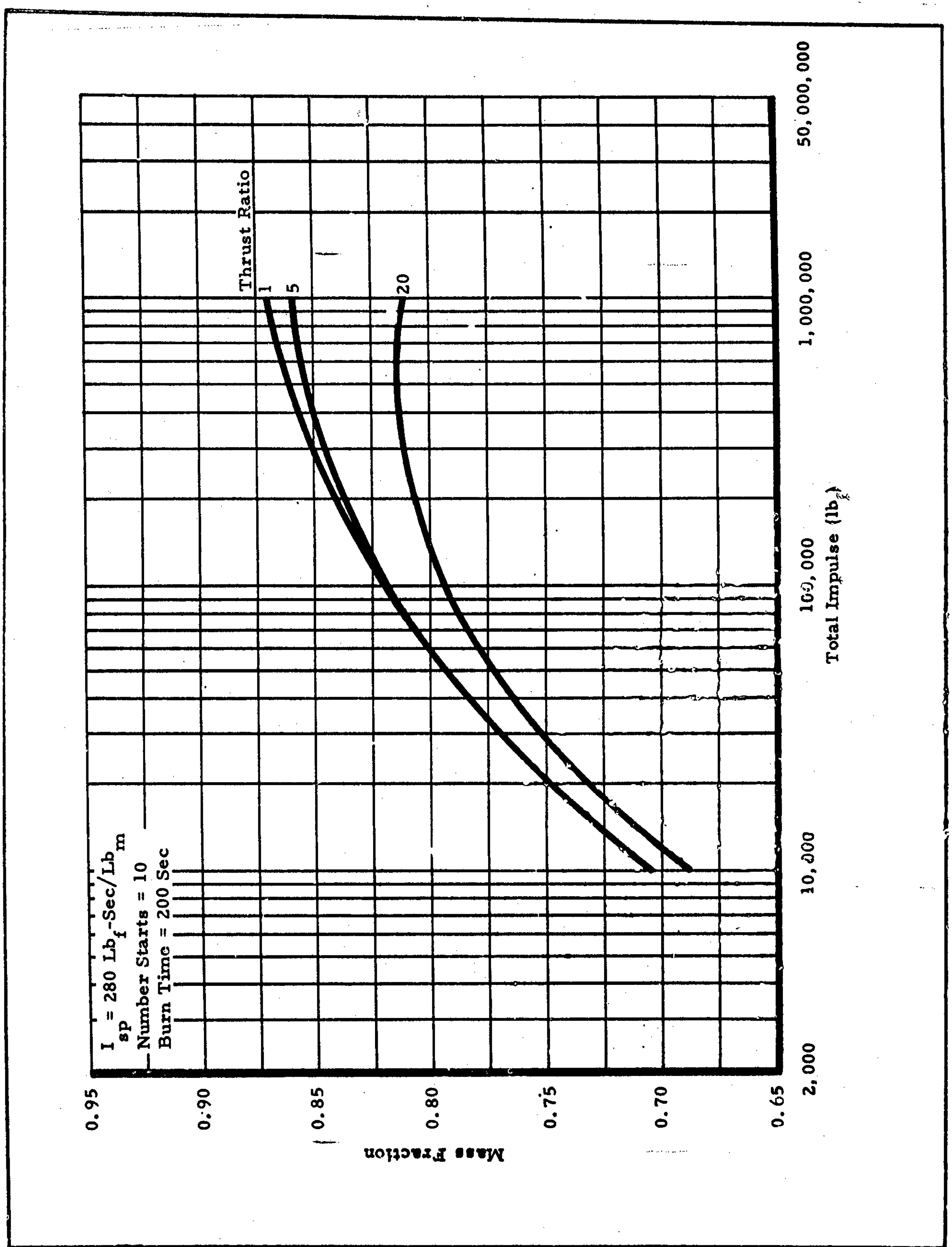

Figure B-12 - Mass Fraction versus Total Impulse for 200-Sec Burn Time

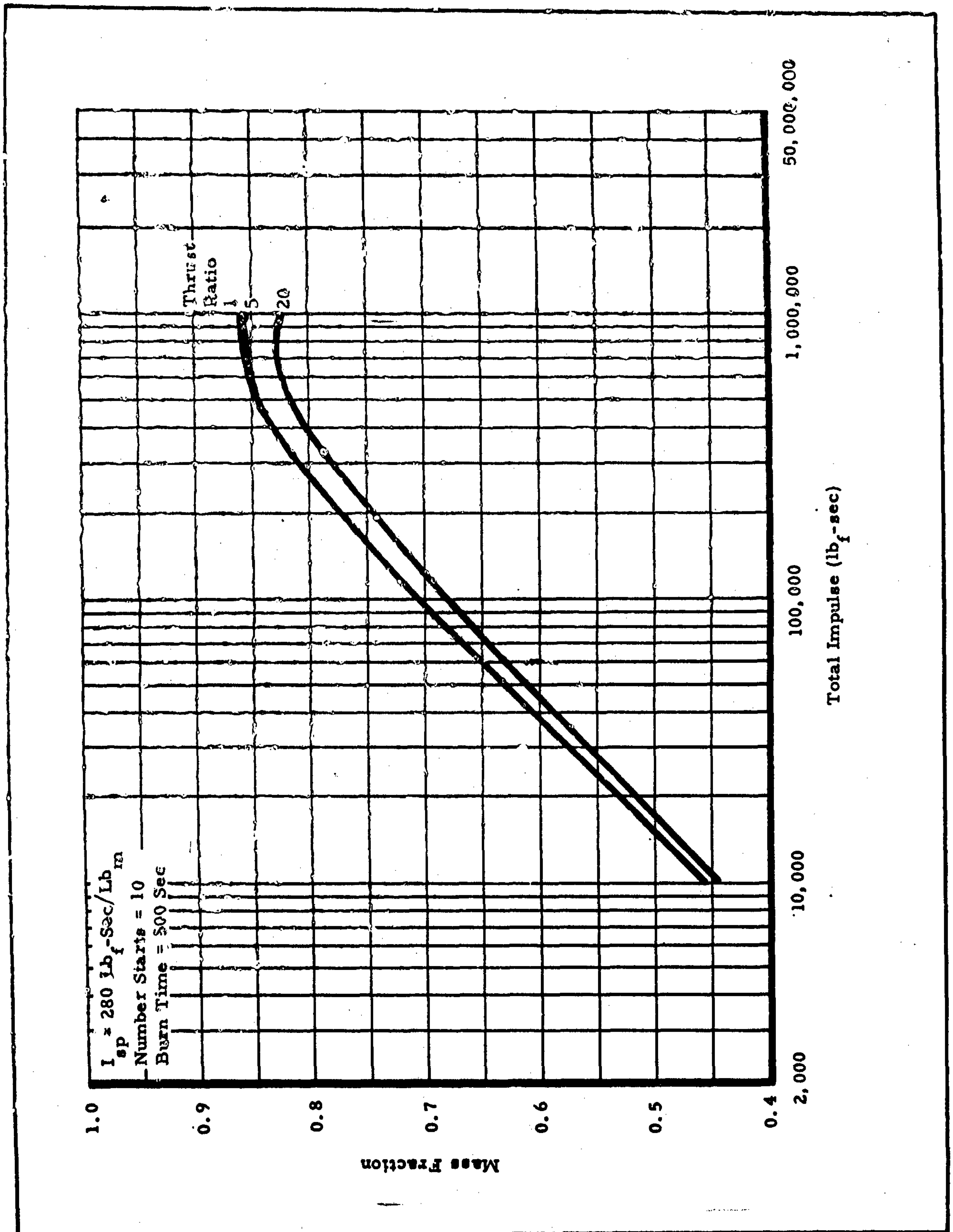

Figure B-13 - Mass Fraction versus Total Impulse for 500-Sec Burn Time

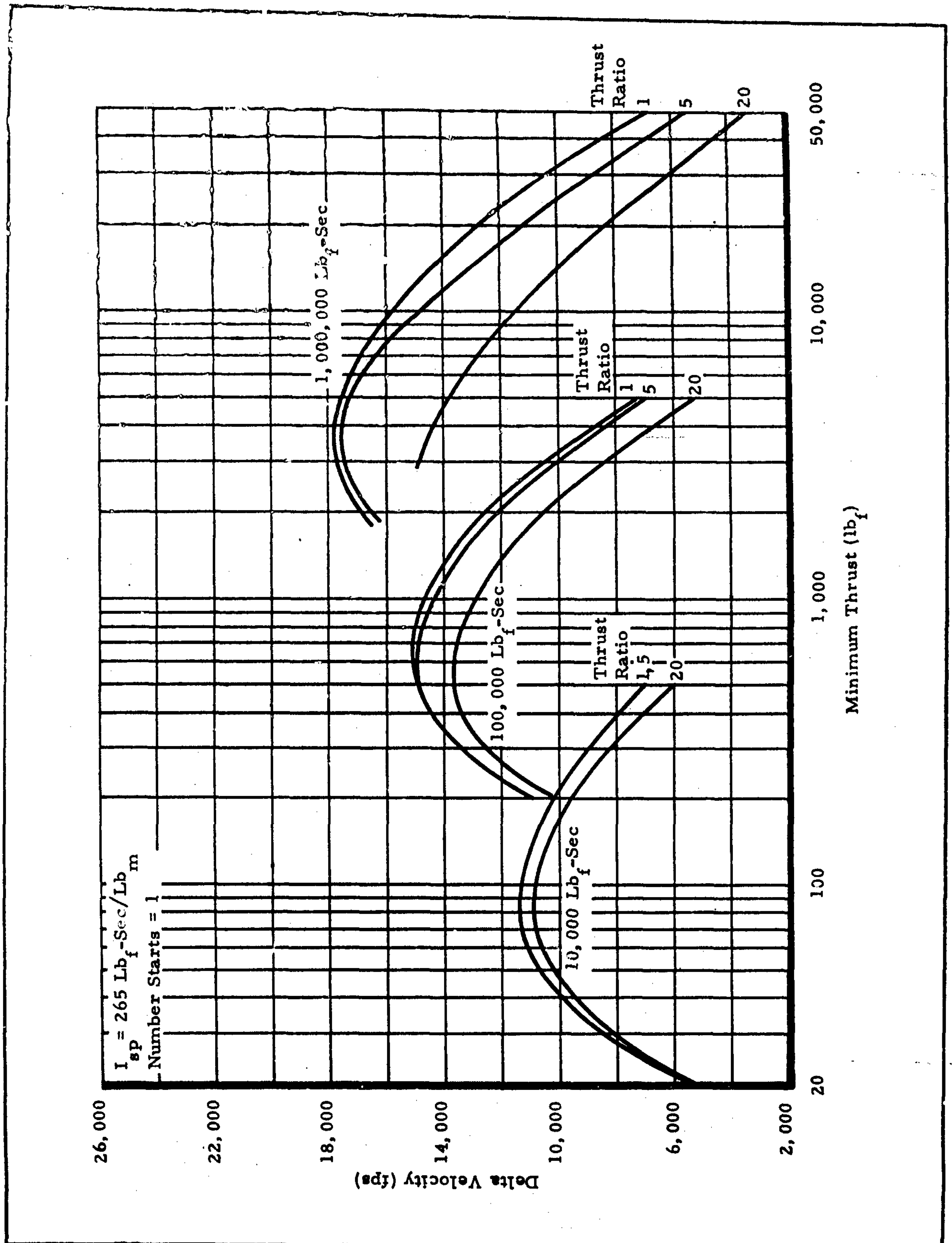

Figure B-14 - Delta Velocity versus Minimum Thrust for I_{sp} = 265 Lb_f-Sec/Lb_m and 1 Start

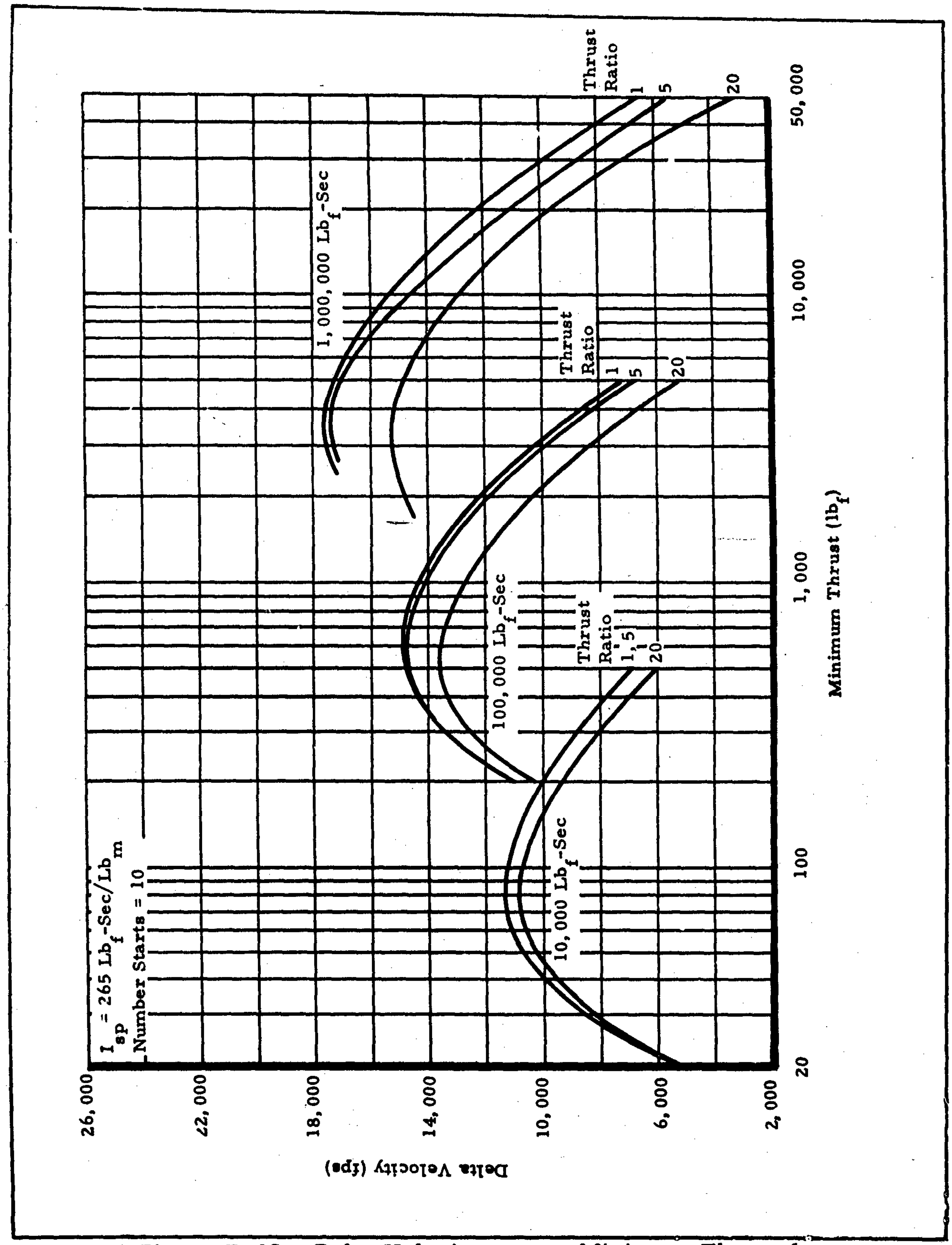

Figure B-15 - Delta Velocity versus Minimum Thrust for I_{sp} = 265 Lb_f-Sec/Lb_m and 10 Starts

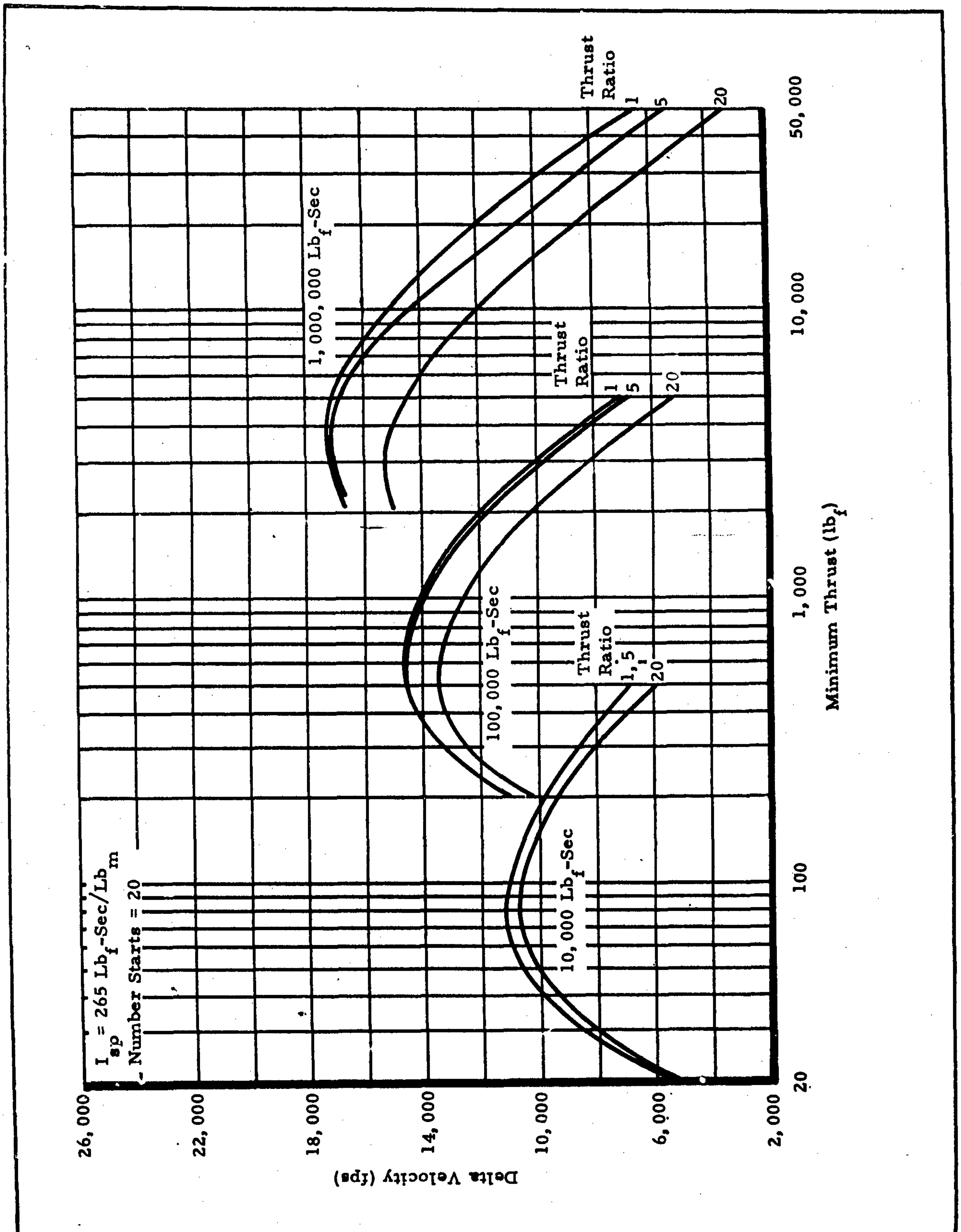

Figure B-16 - Delta Velocity versus Minimum Thrust for I_{sp} = 265 Lb_f-Sec/Lb_m and 20 Starts

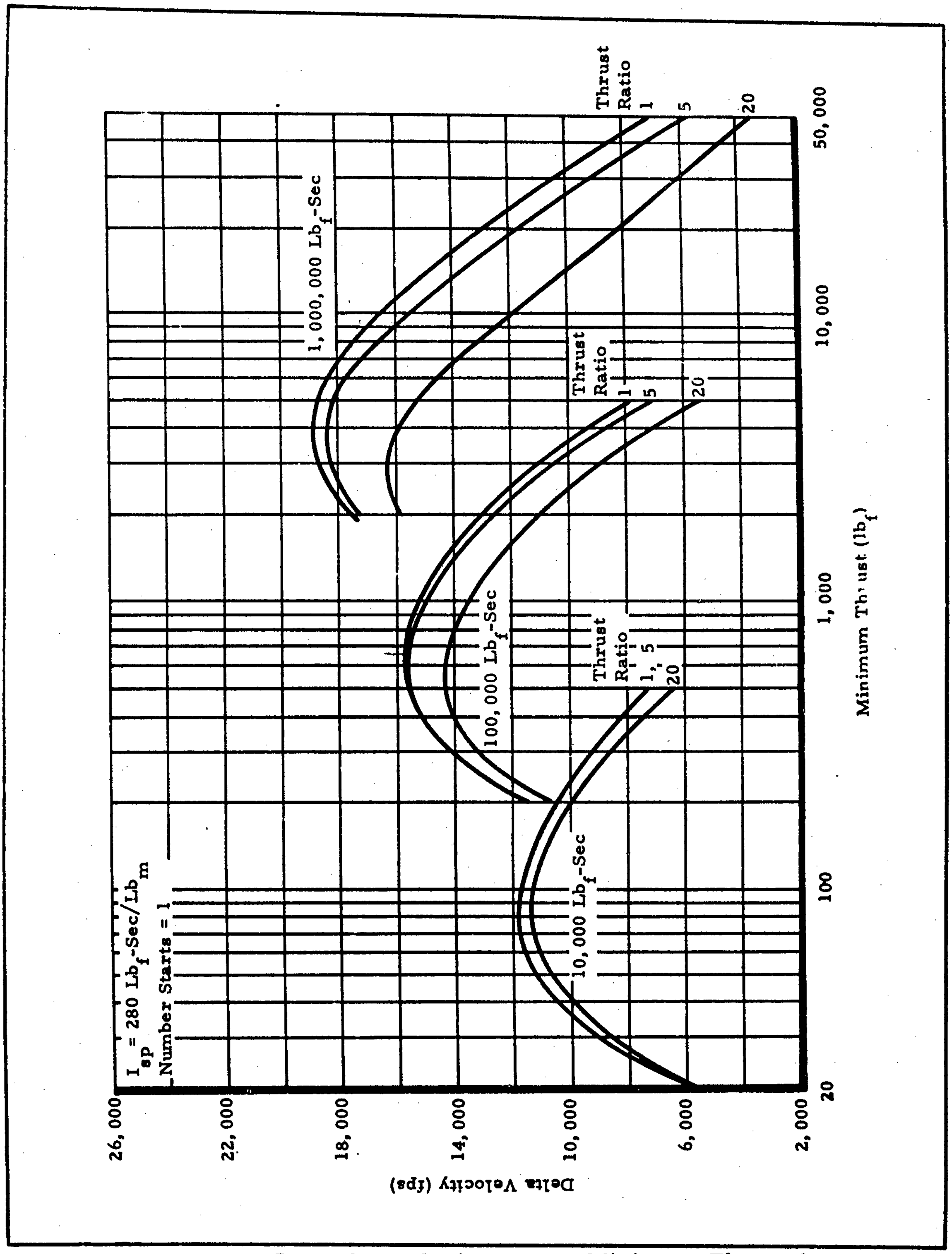

Figure B-17 - Delta Velocity versus Minimum Thrust for I_{sp} = 280 Lb_f-Sec/Lb_m and 1 Start

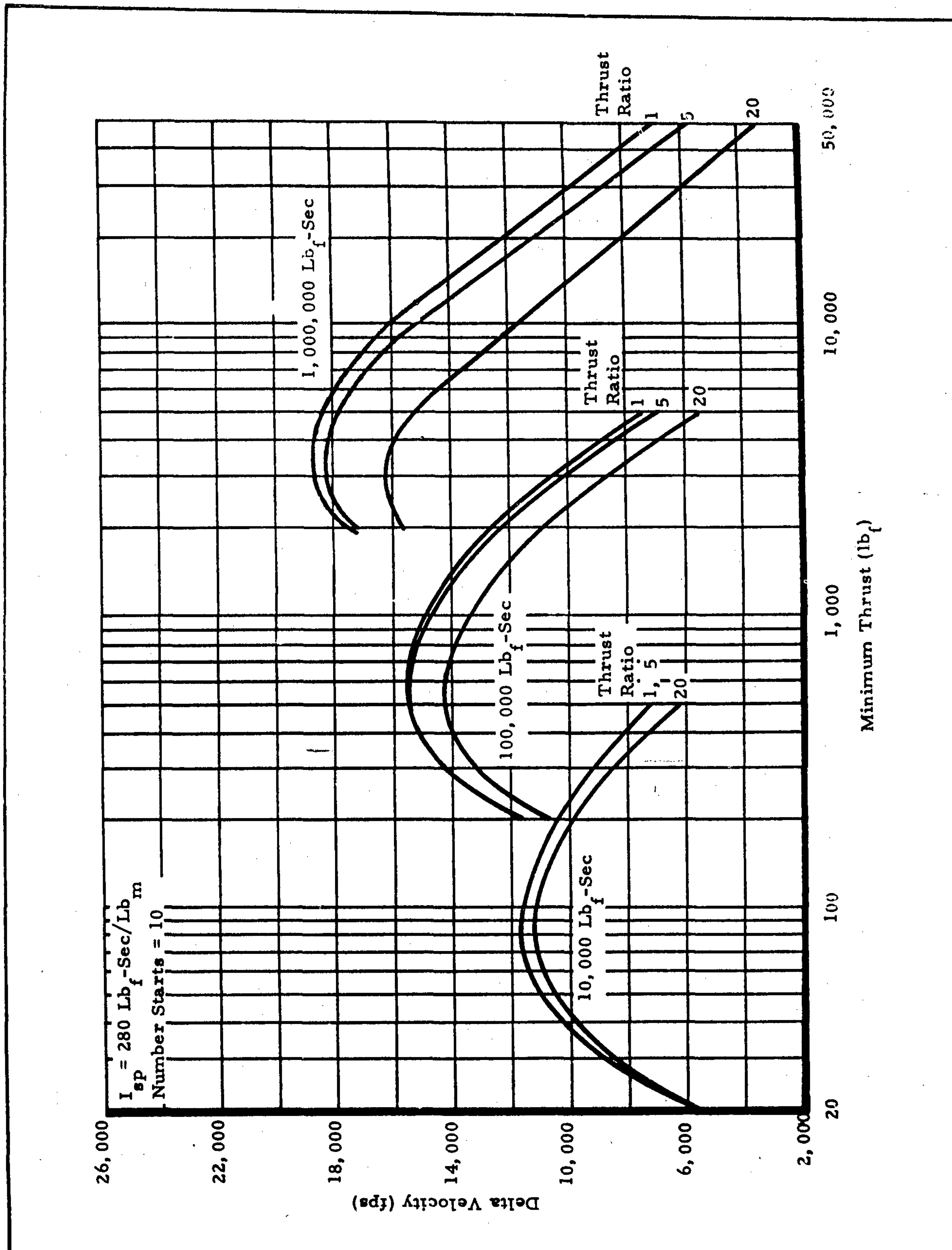

Figure B-18 - Delta Velocity versus Minimum Thrust for I_{sp} = 280 Lb$_f$-Sec/Lb$_m$ and 10 Starts

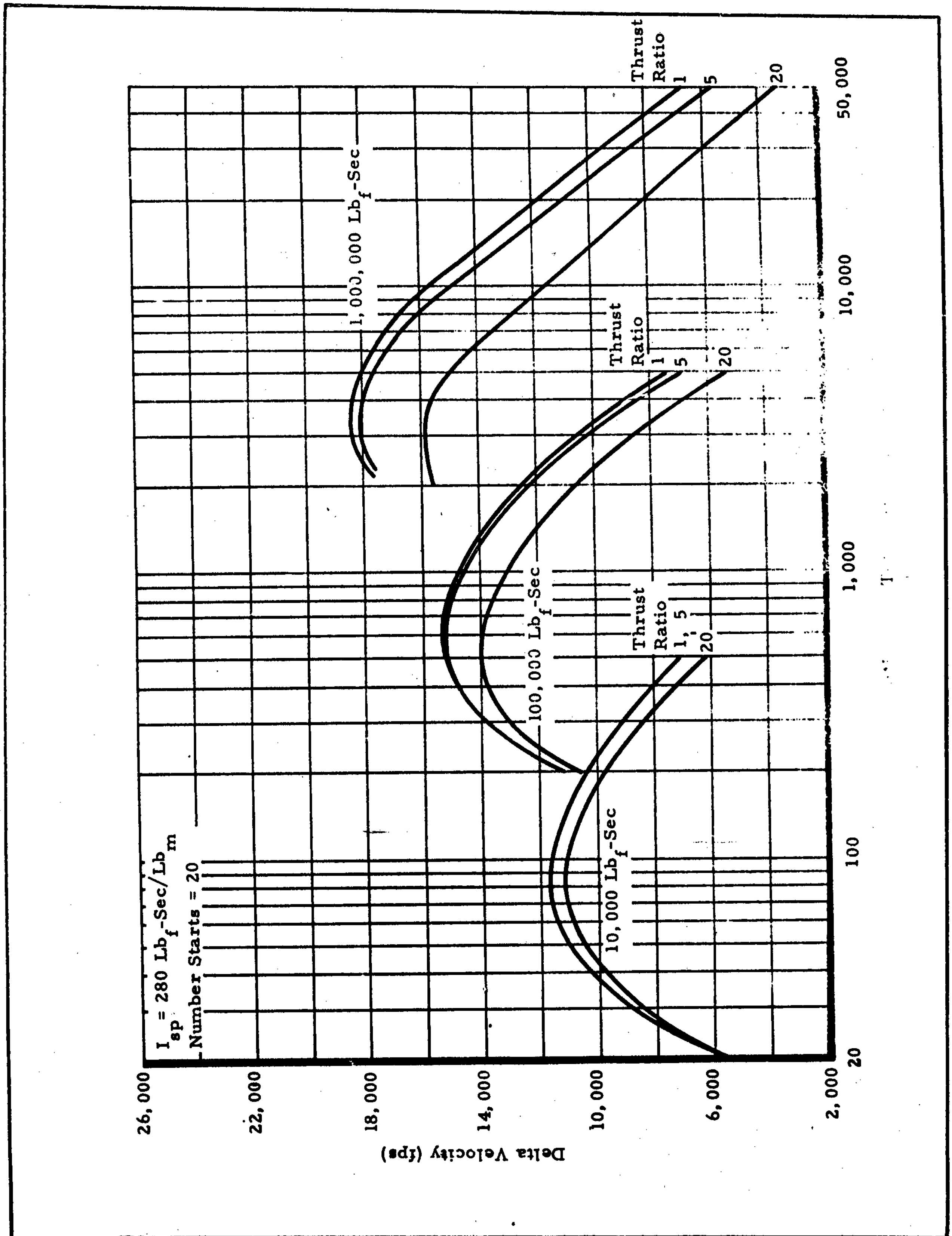

Figure B-19 - Delta Velocity versus Minimum Thrust for I_{sp} = 280 Lb_f-Sec/Lb_m and 20 Starts

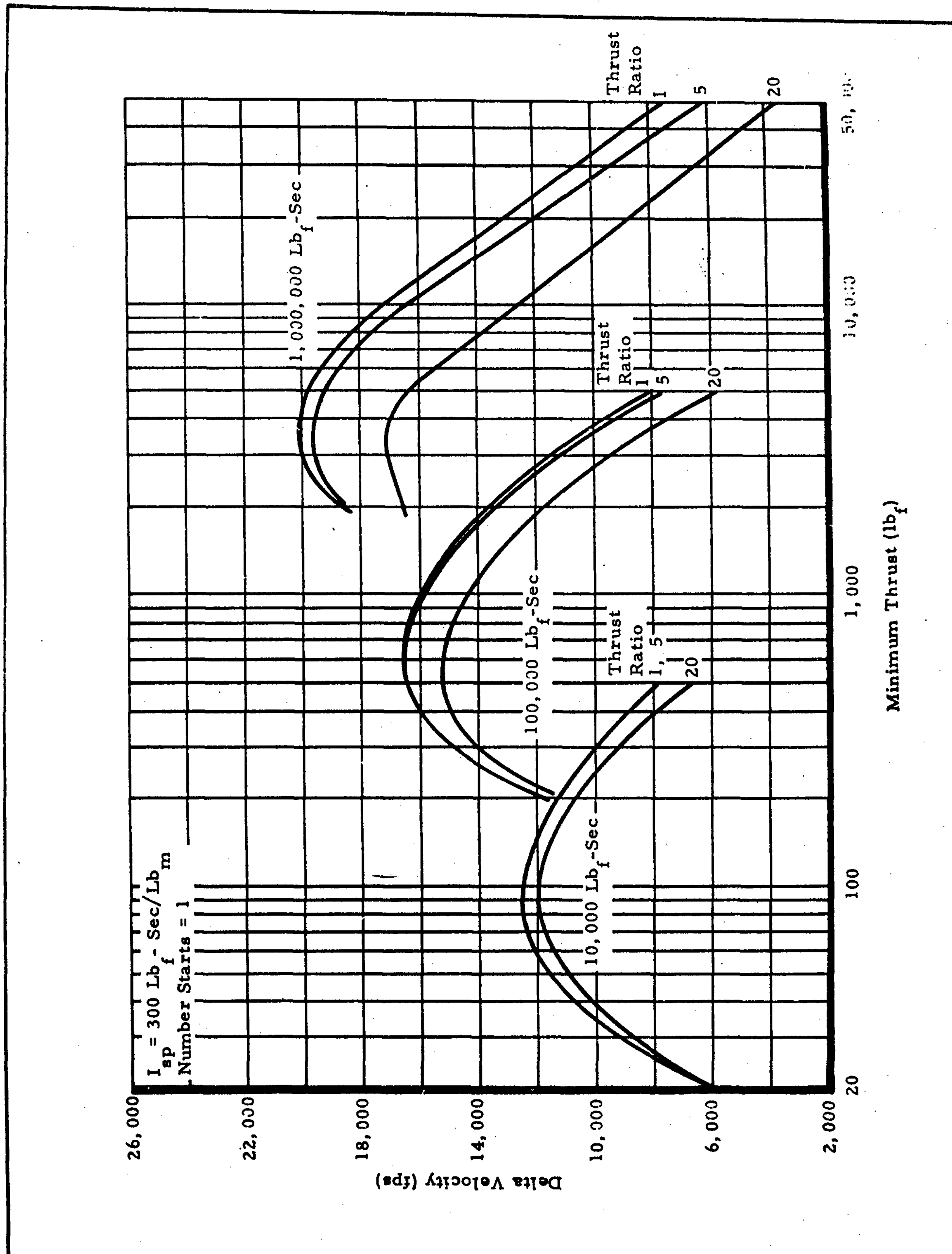

Figure B-20 - Delta Velocity versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m and 1 Start

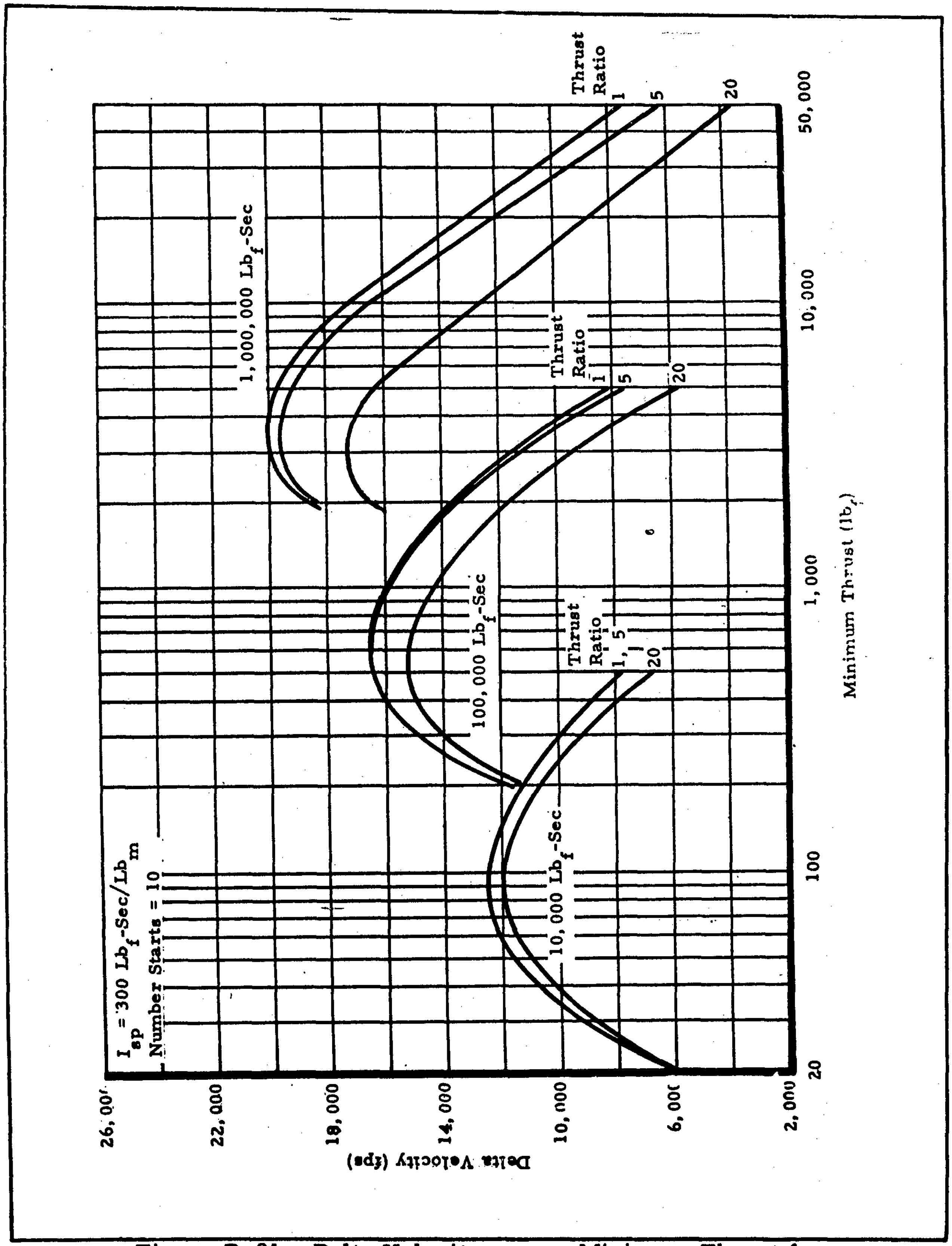

Figure B-21 - Delta Velocity versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m and 10 Starts

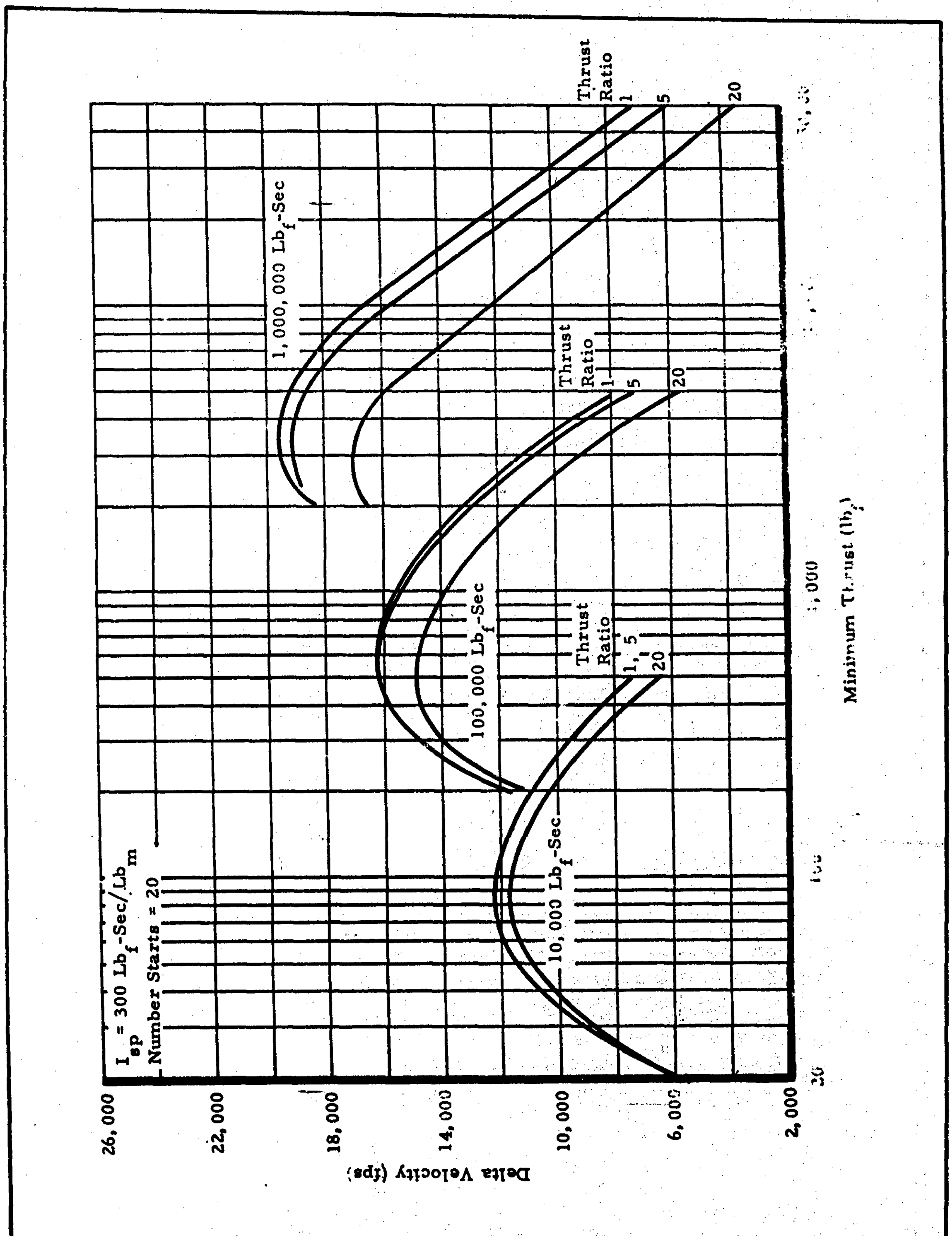

Figure B-22 - Delta Velocity versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m and 20 Starts

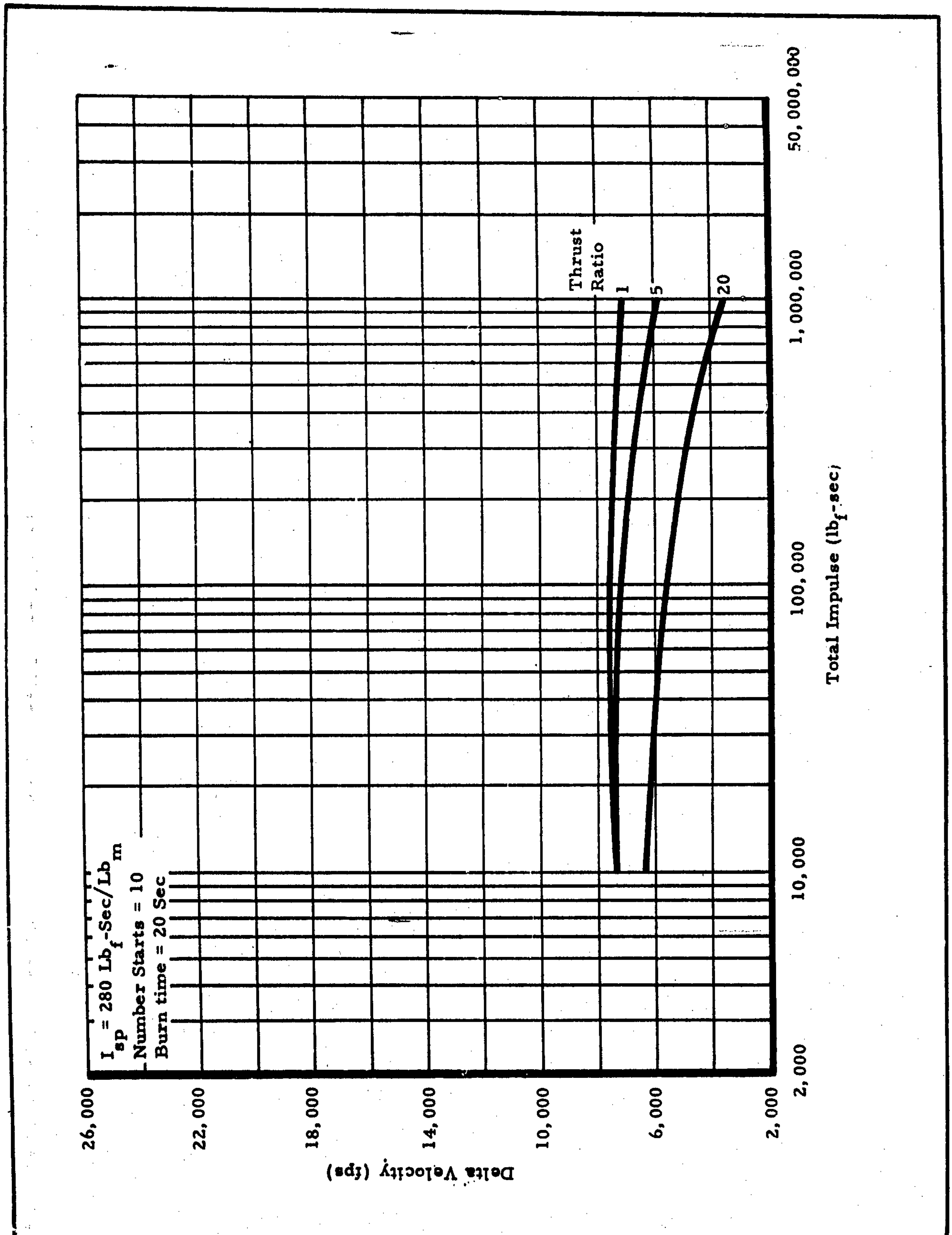

Figure B-23 - Delta Velocity versus Total Impulse for 20-Sec Burn Time

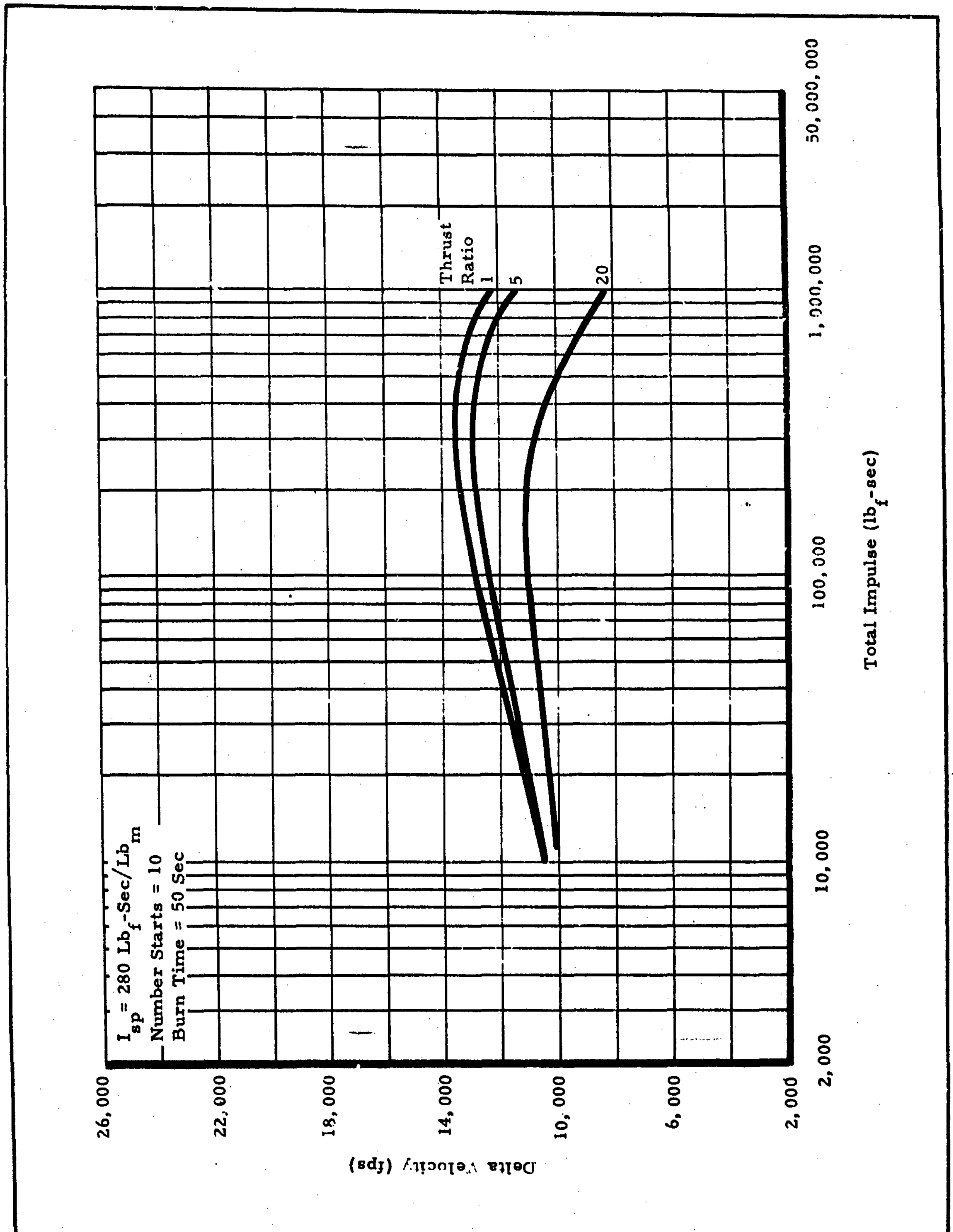

Figure B-24 - Delta Velocity versus Total Impulse for 50-Sec Burn Time

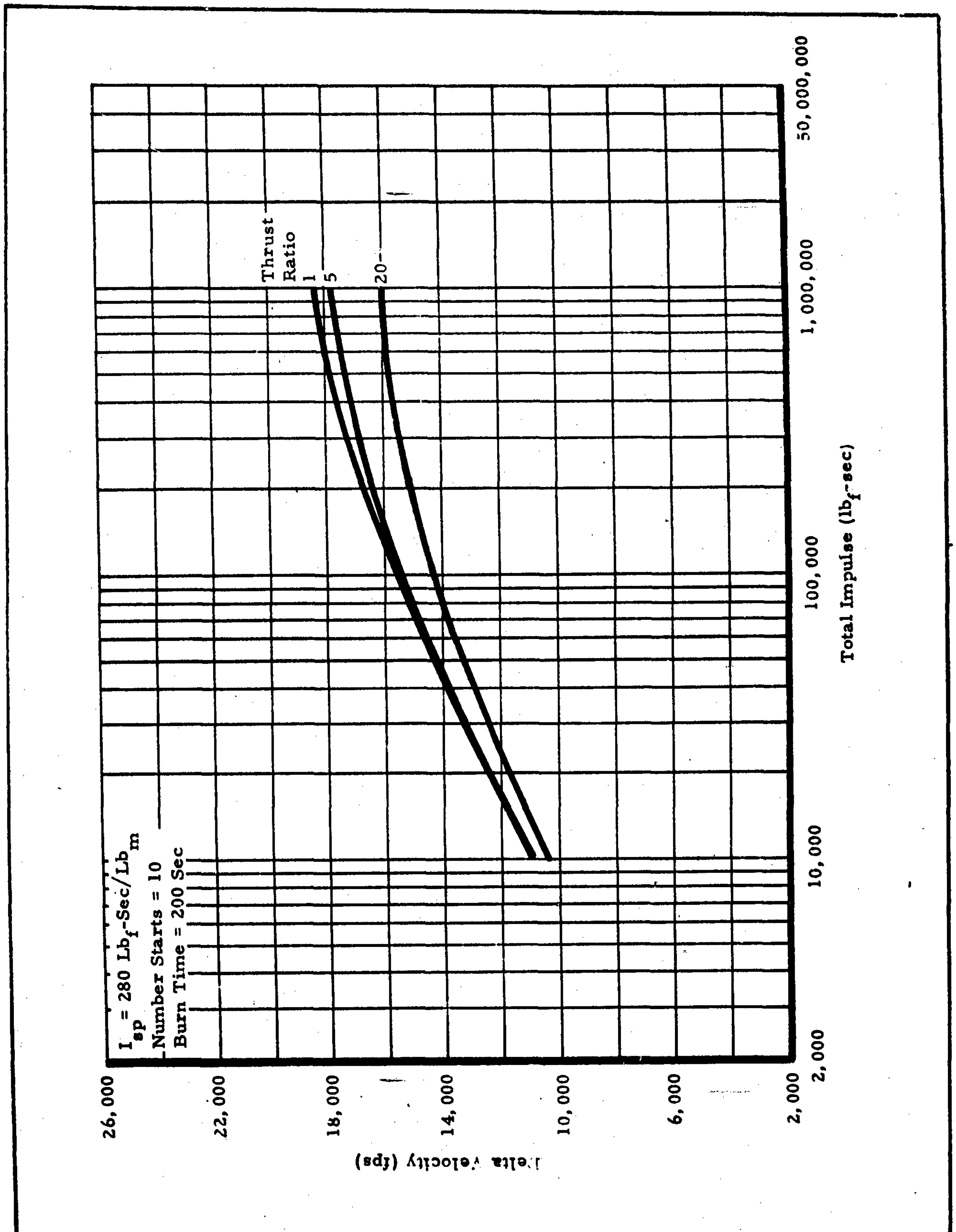

Figure B-25 - Delta Velocity versus Total Impulse for 200-Sec Burn Time

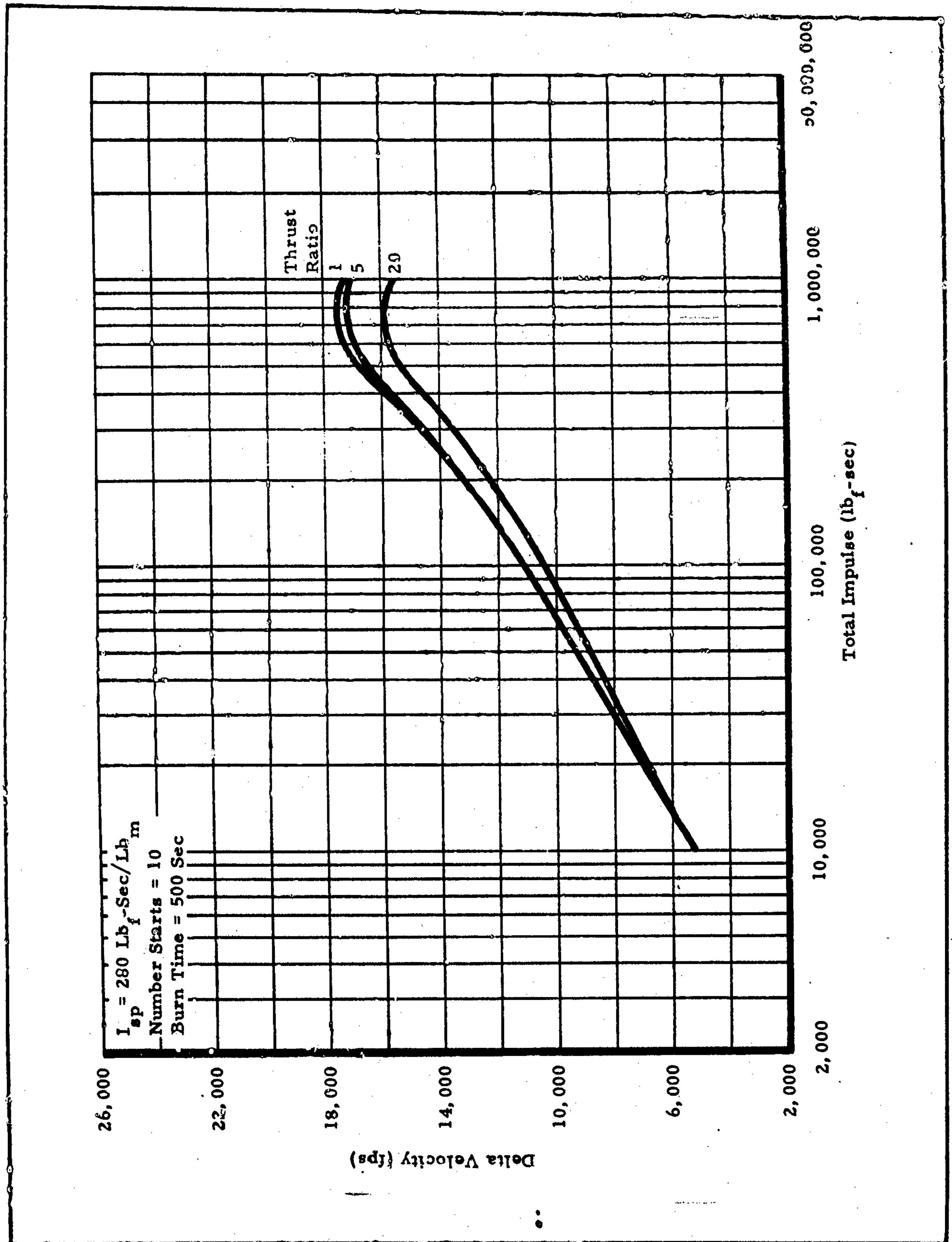

Figure B-26 - Delta Velocity versus Total Impulse for 500-Sec Burn Time

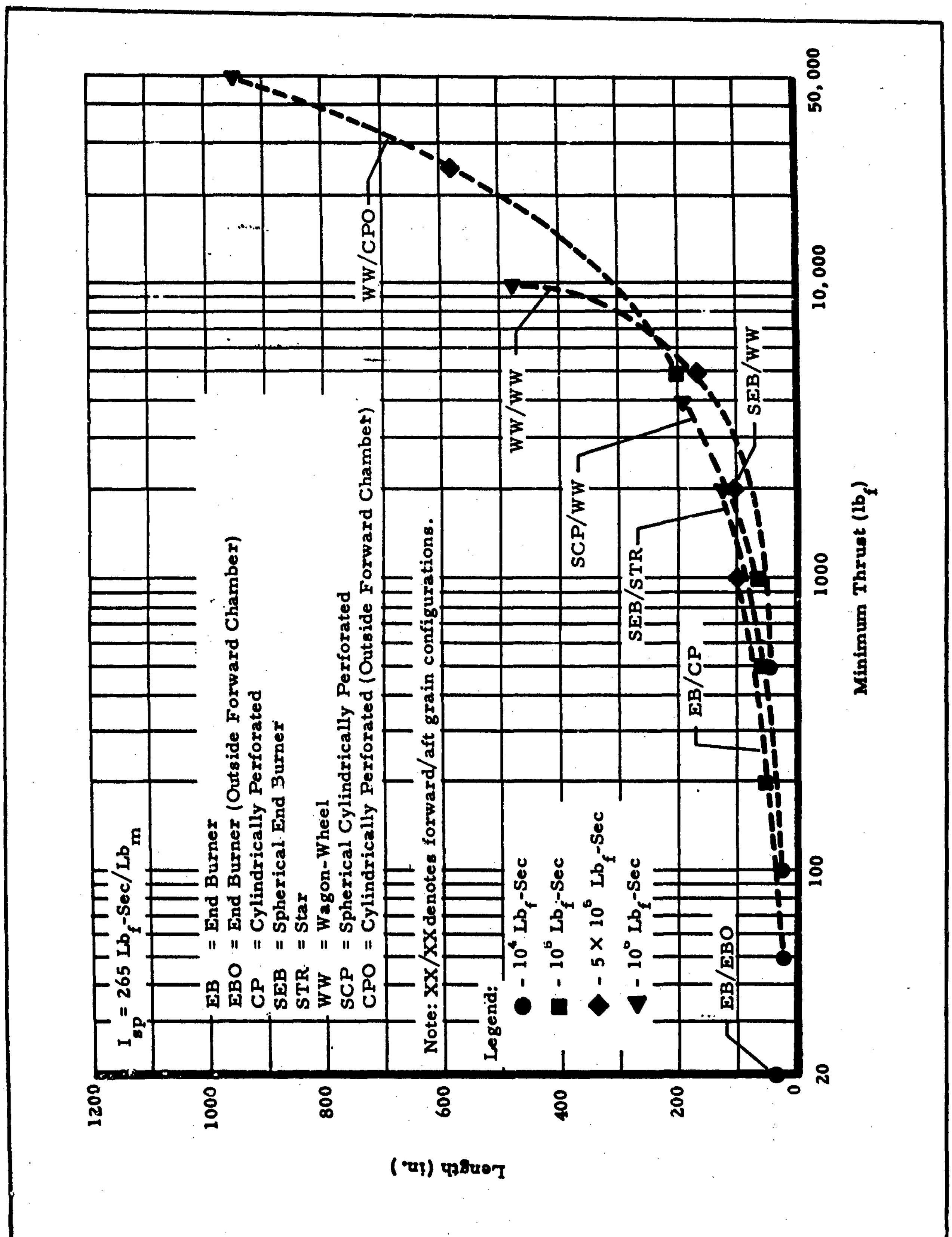

Figure B-27 - Length versus Minimum Thrust for I_{sp} = 265 Lb_f-Sec/Lb_m

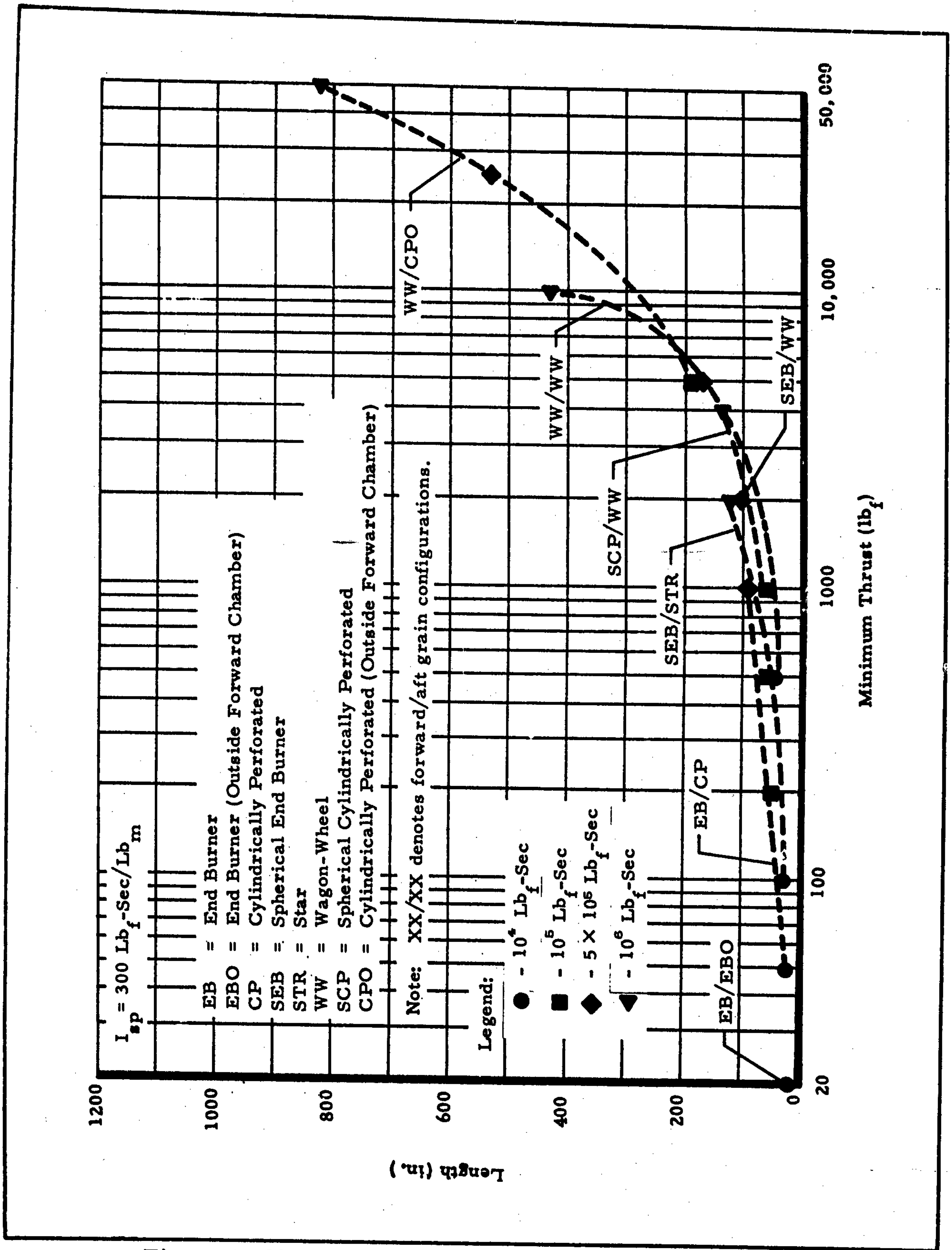

Figure B-28 - Length versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m

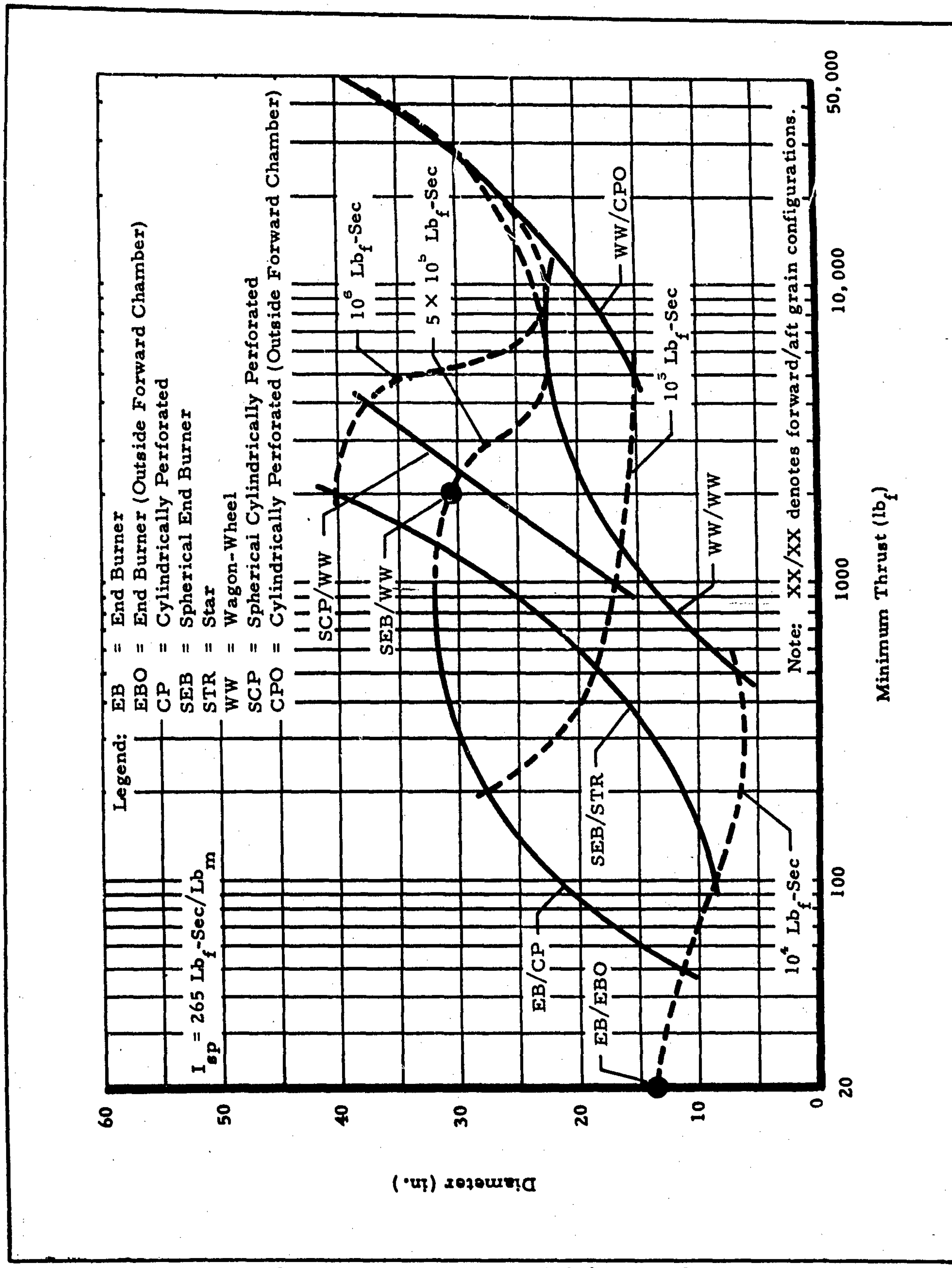

Figure B-29 - Diameter versus Minimum Thurst for I_{sp} = 265 Lb_f-Sec/Lb_m

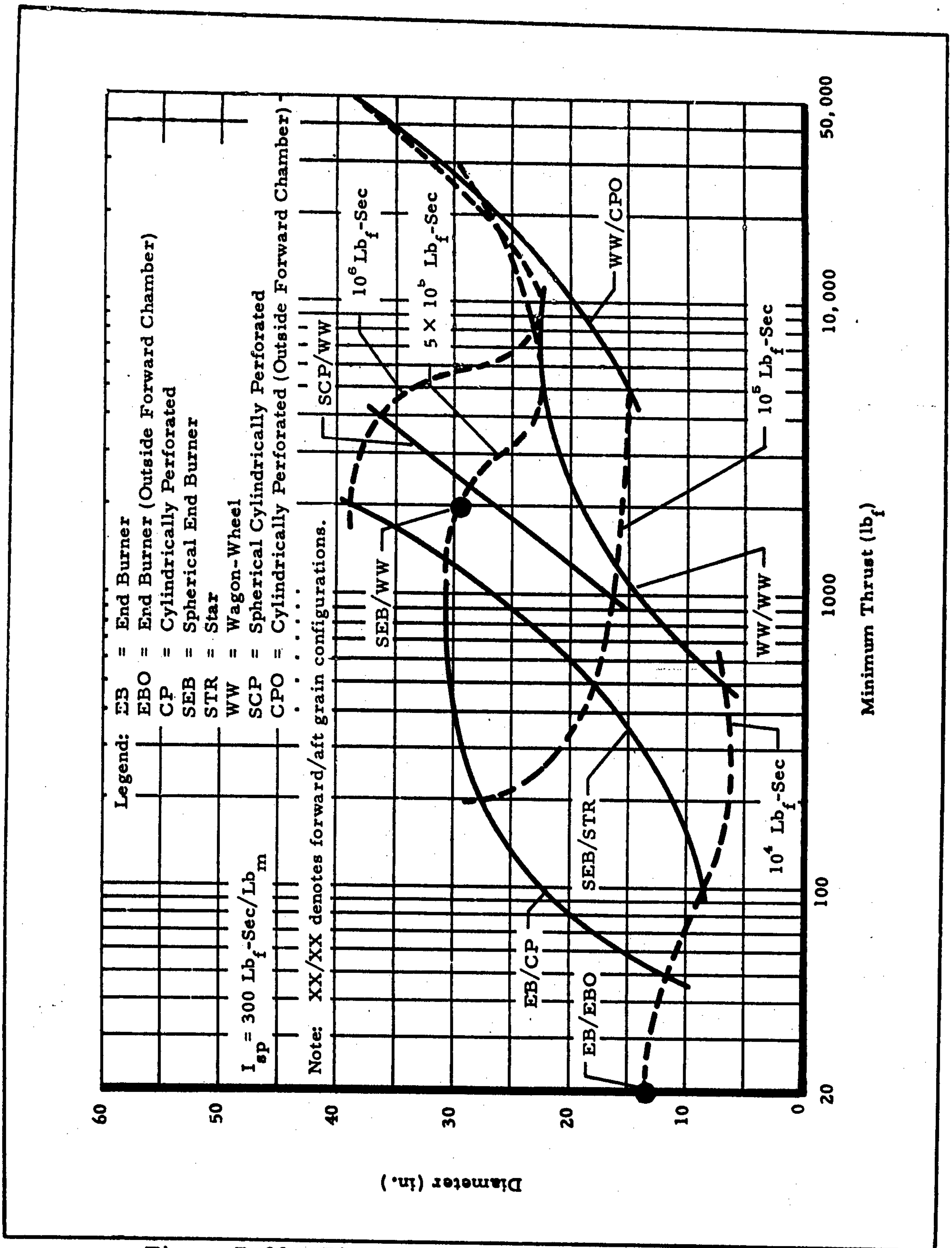

Figure B-30 - Diameter versus Minimum Thrust for I_{sp} = 300 Lb_f-Sec/Lb_m

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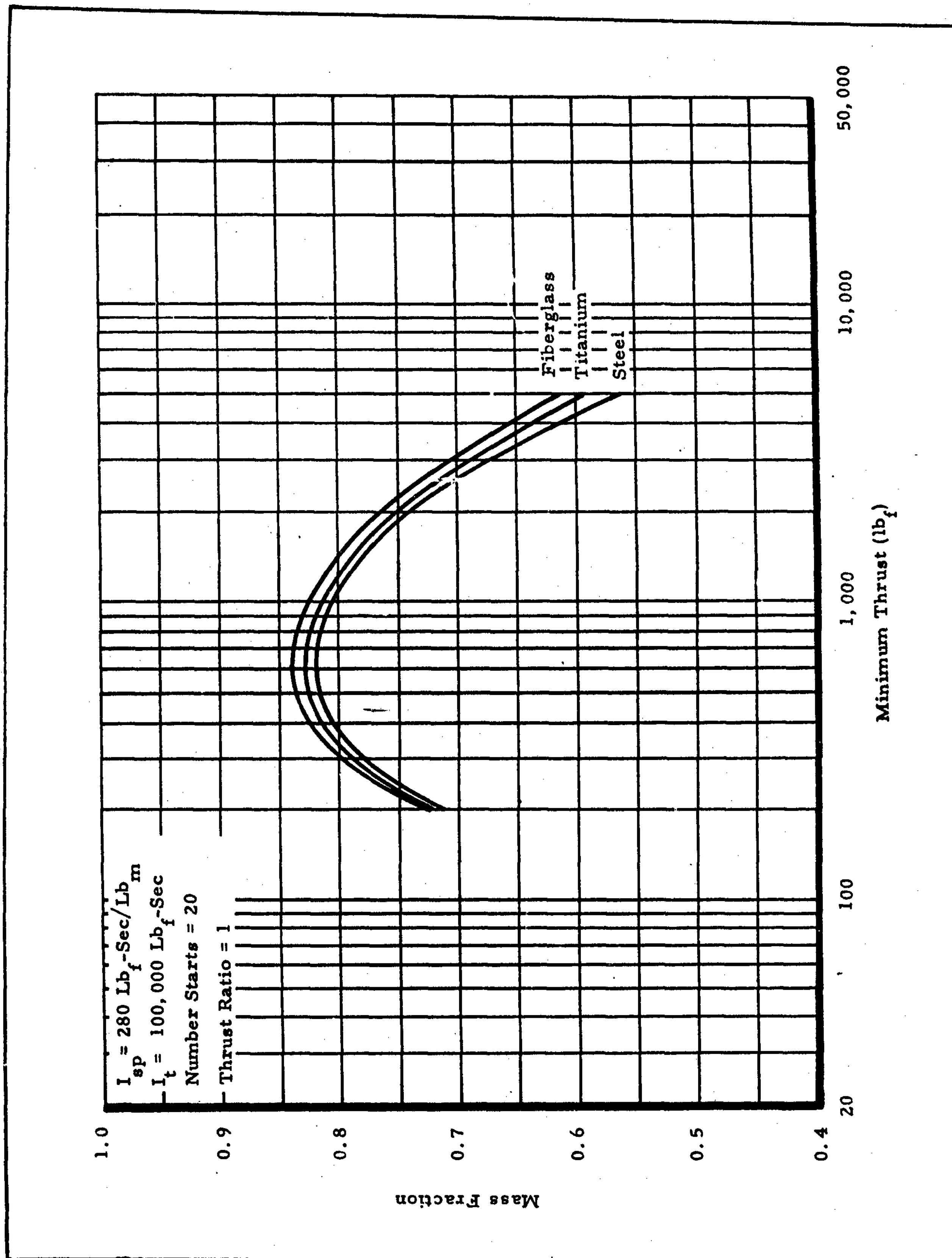


Figure B-31 - Mass Fraction versus Minimum Thrust at Thrust Ratio of 1

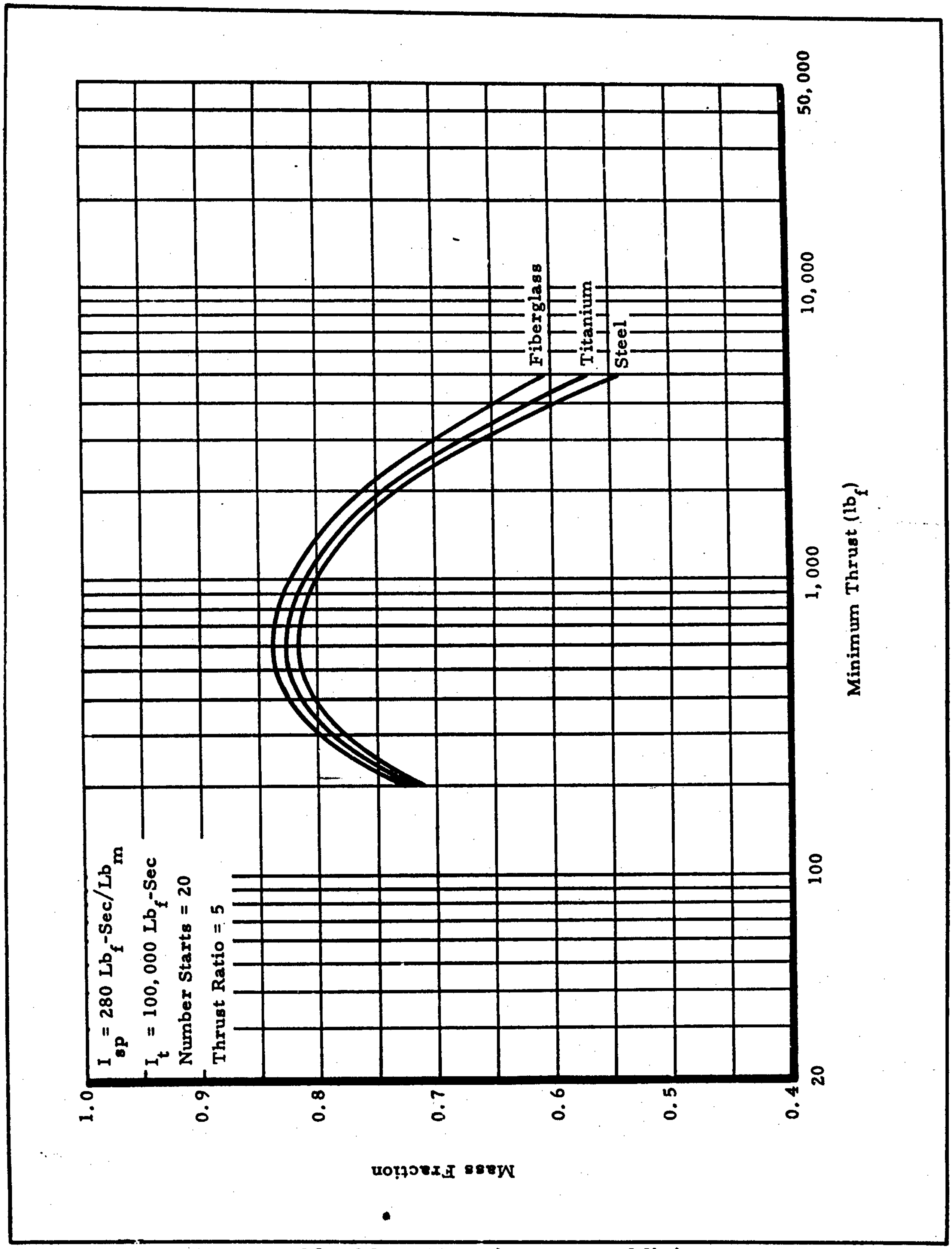


Figure B-32 - Mass Fraction versus Minimum Thrust at Thrust Ratio of 5

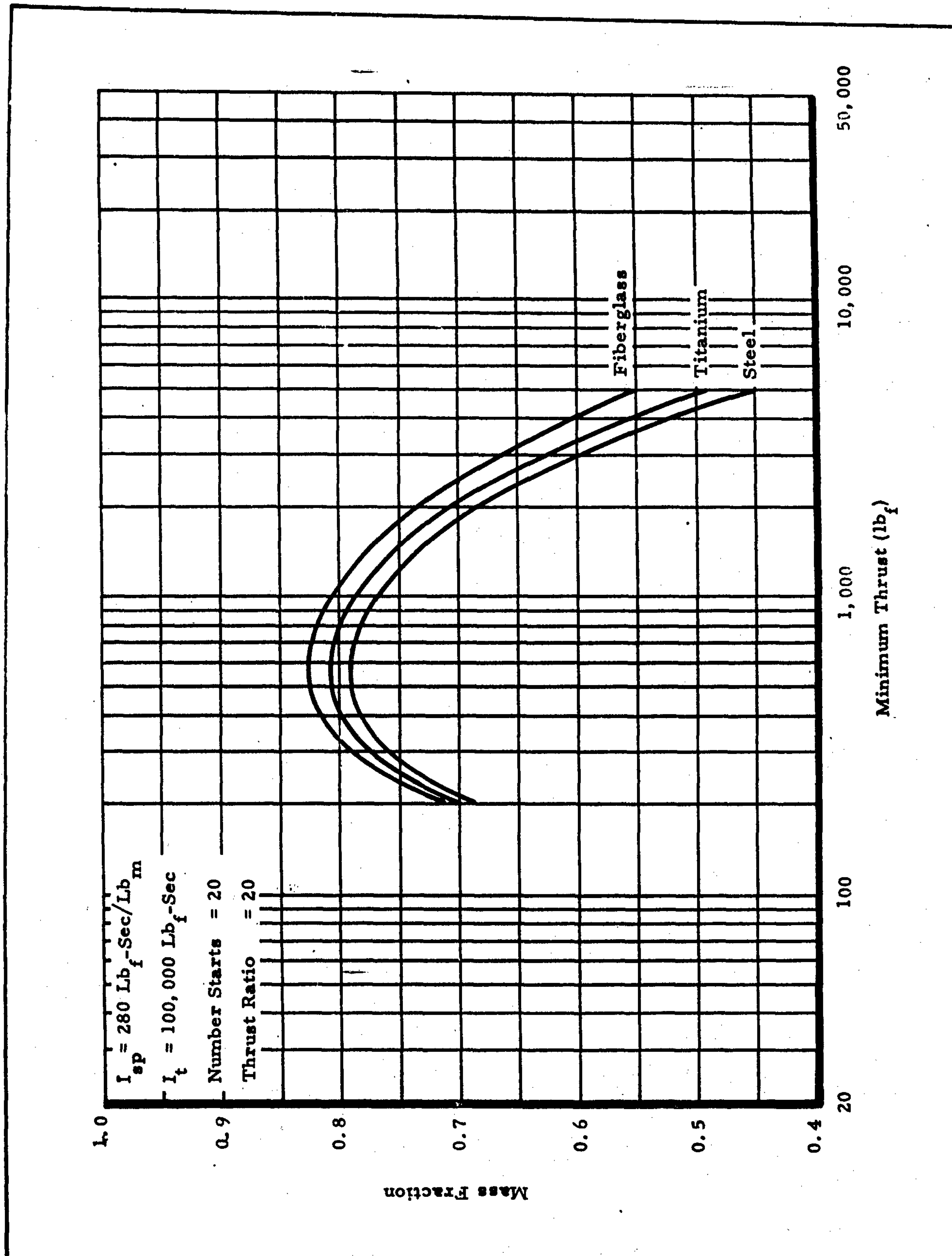


Figure B-33 - Mass Fraction versus Minimum Thrust at Thrust Ratio of 20

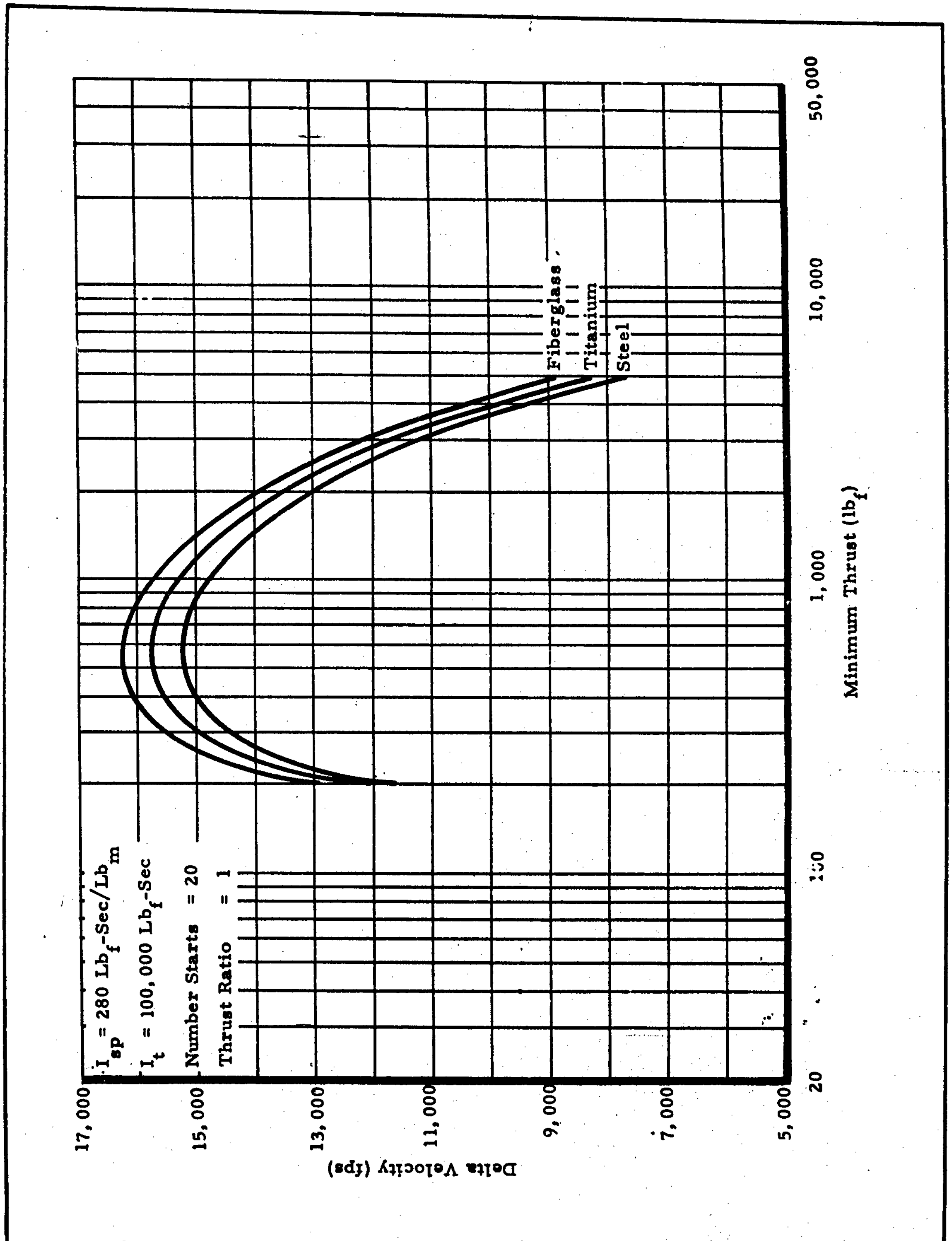


Figure B-34 - Delta Velocity versus Minimum Thrust at Thrust Ratio of 1

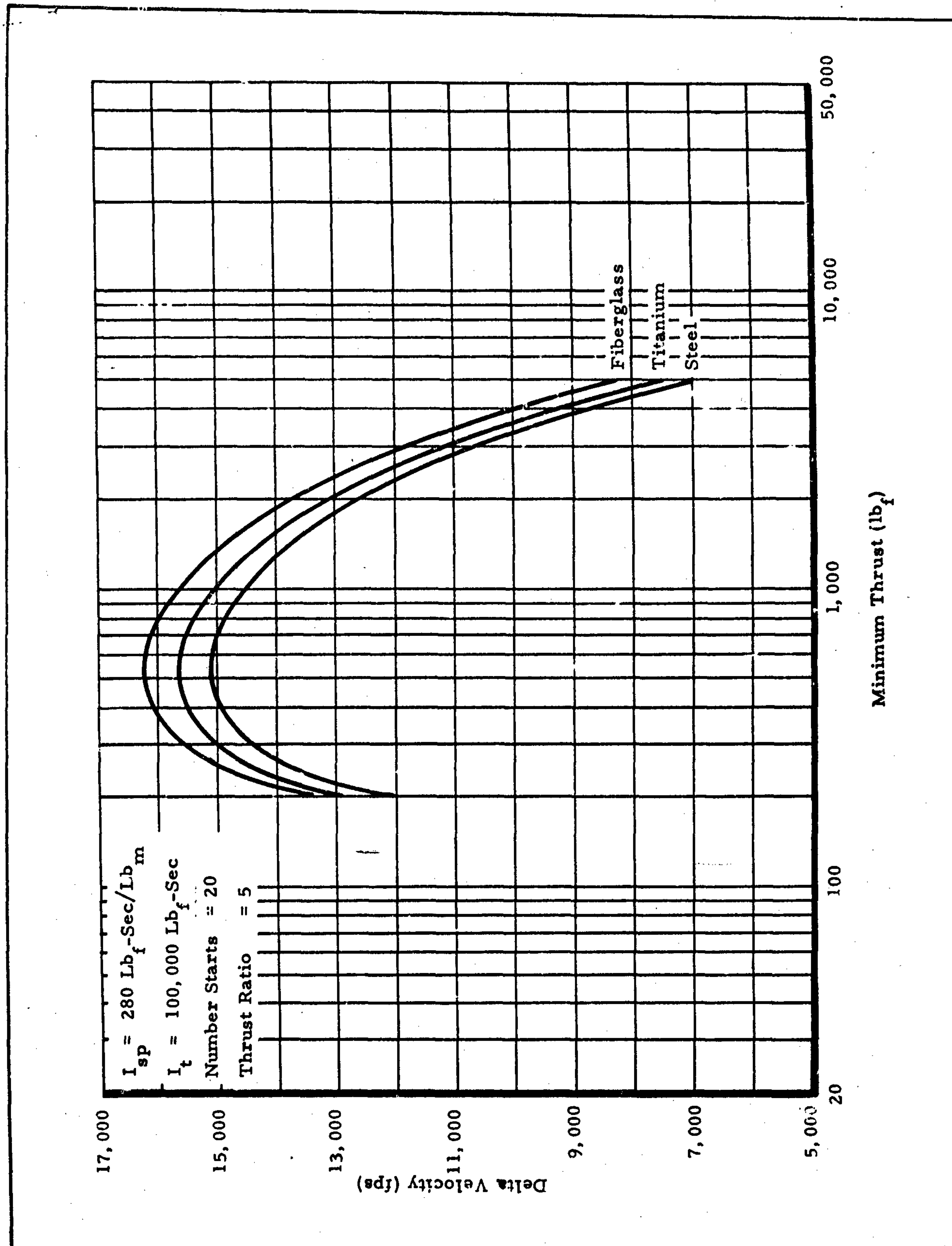


Figure B-35 - Delta Velocity versus Minimum Thrust at Thrust Ratio of 5

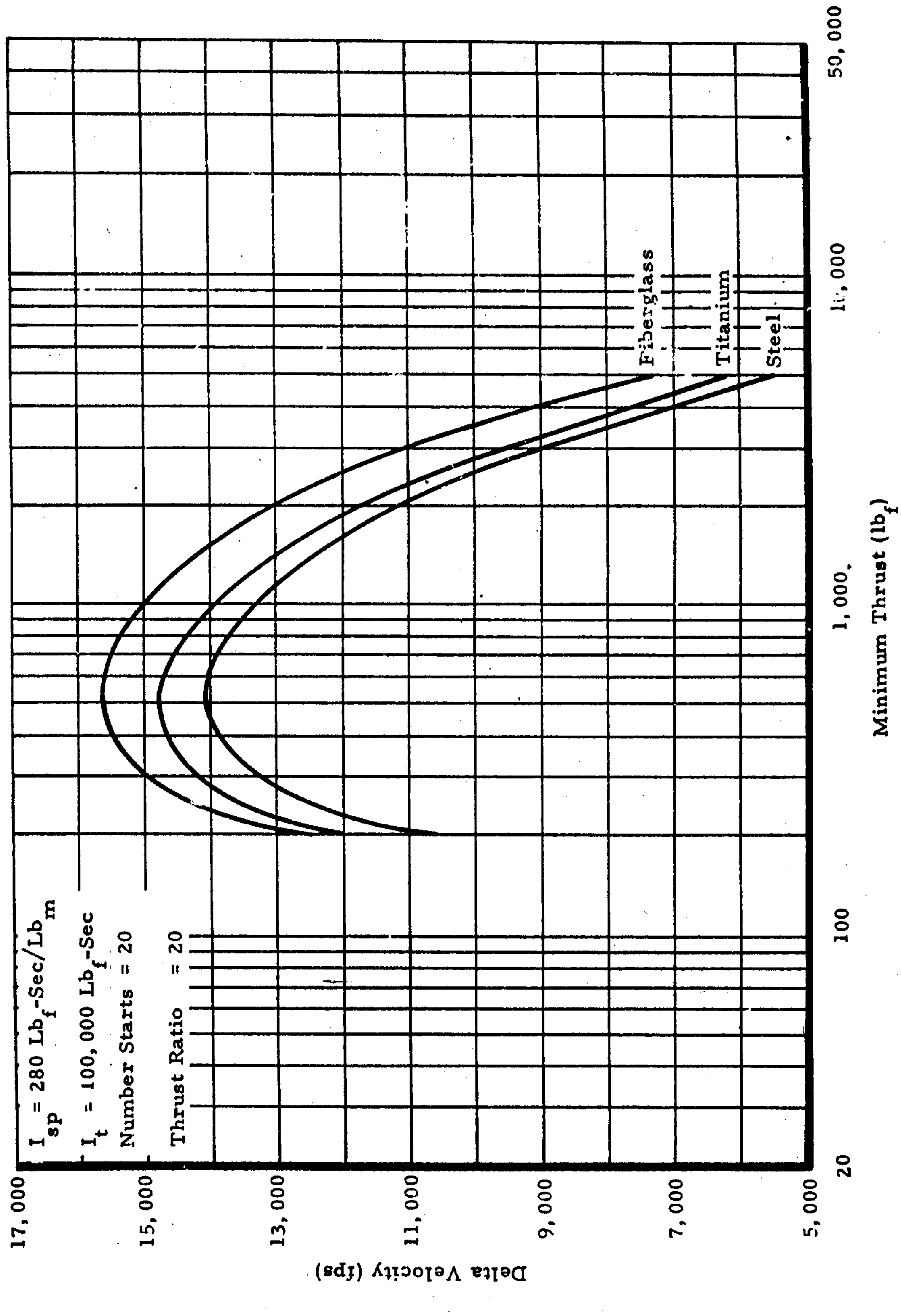


Figure B-36 - Delta Velocity versus Minimum Thrust at Thrust Ratio of 20

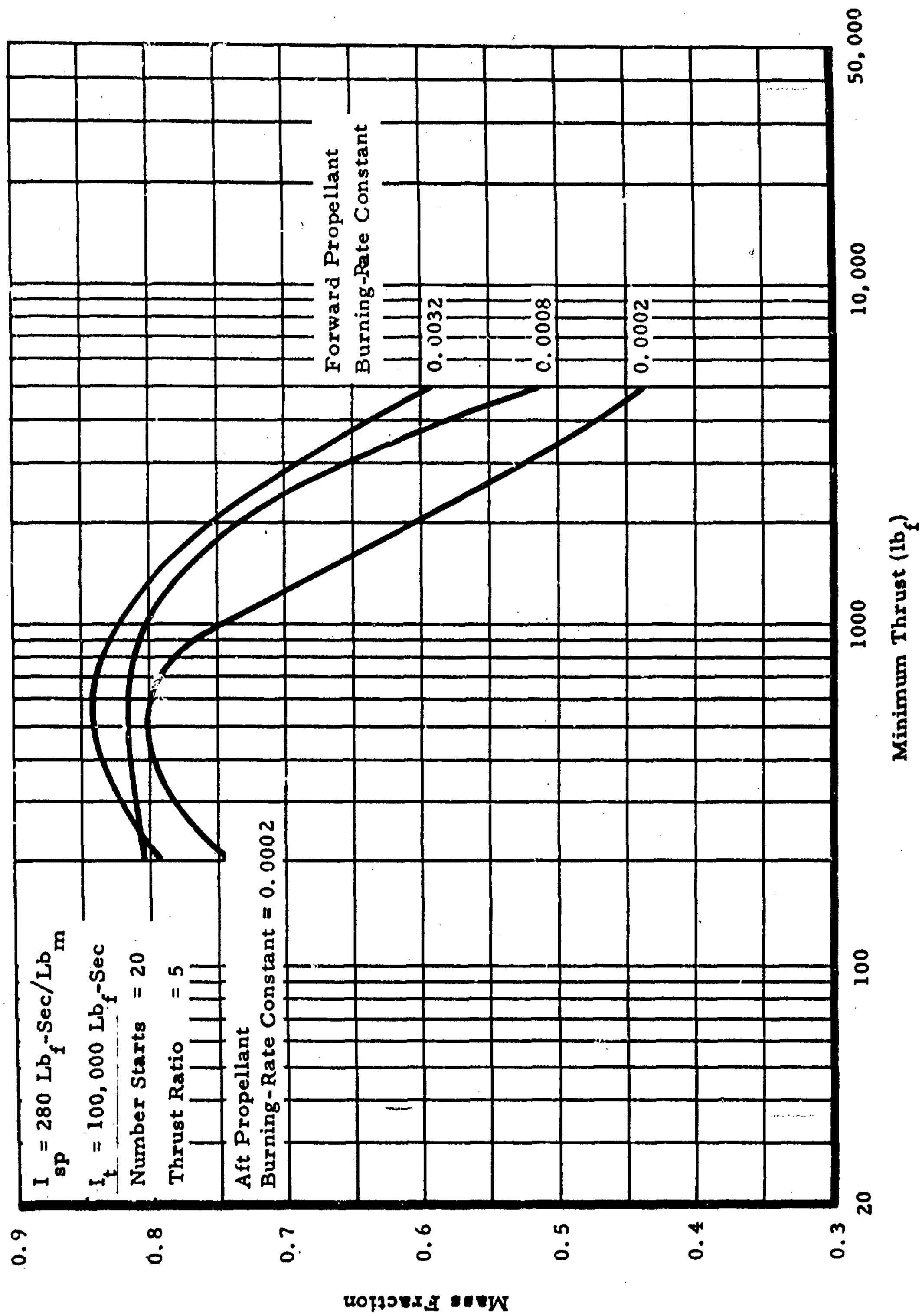


Figure B-37 - Mass Fraction versus Minimum Thrust for Aft Propellant Burning-Rate Constant of 0.0002

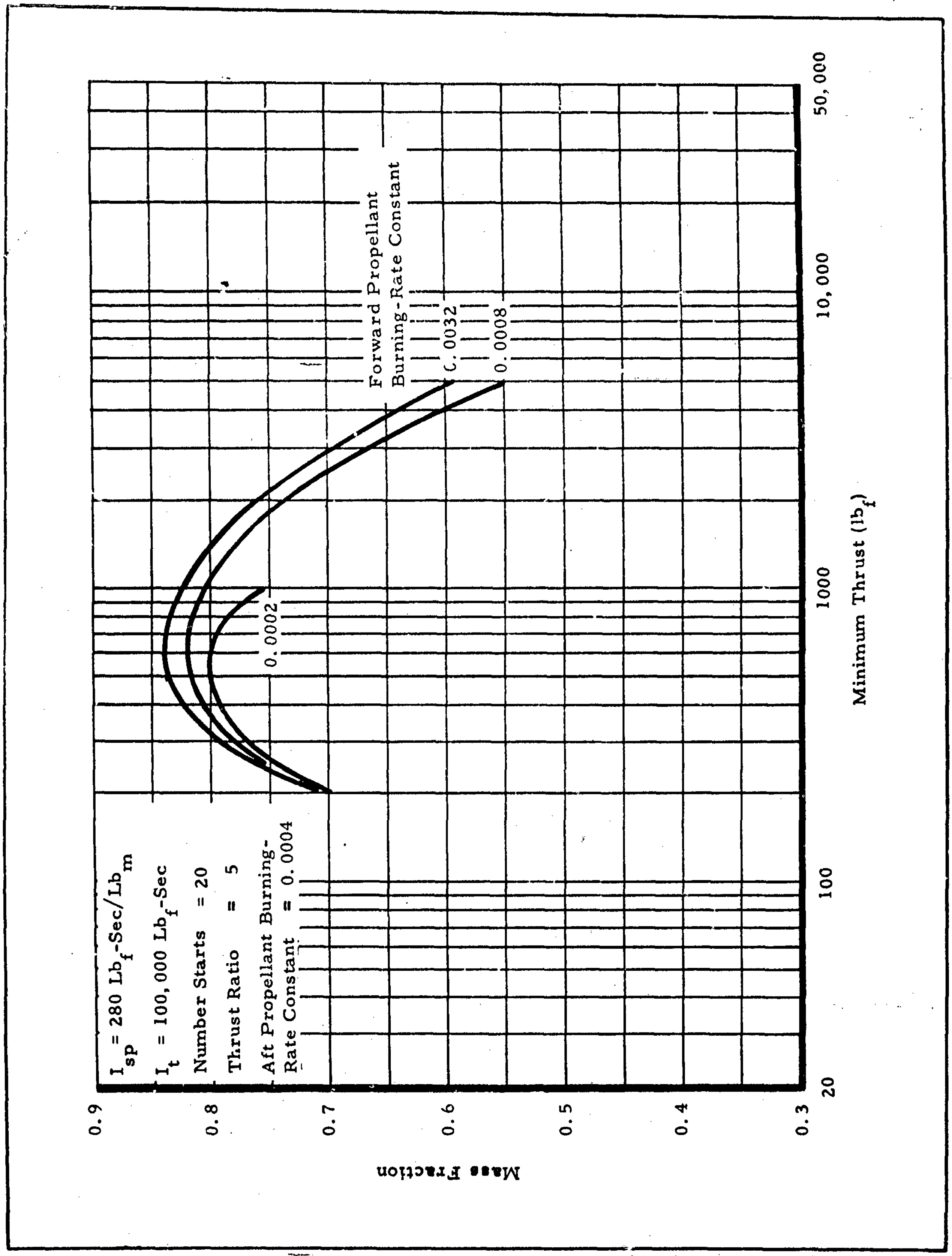


Figure B-38 - Mass Fraction versus Minimum Thrust for Aft Propellant Burning-Rate Constant of 0.0004

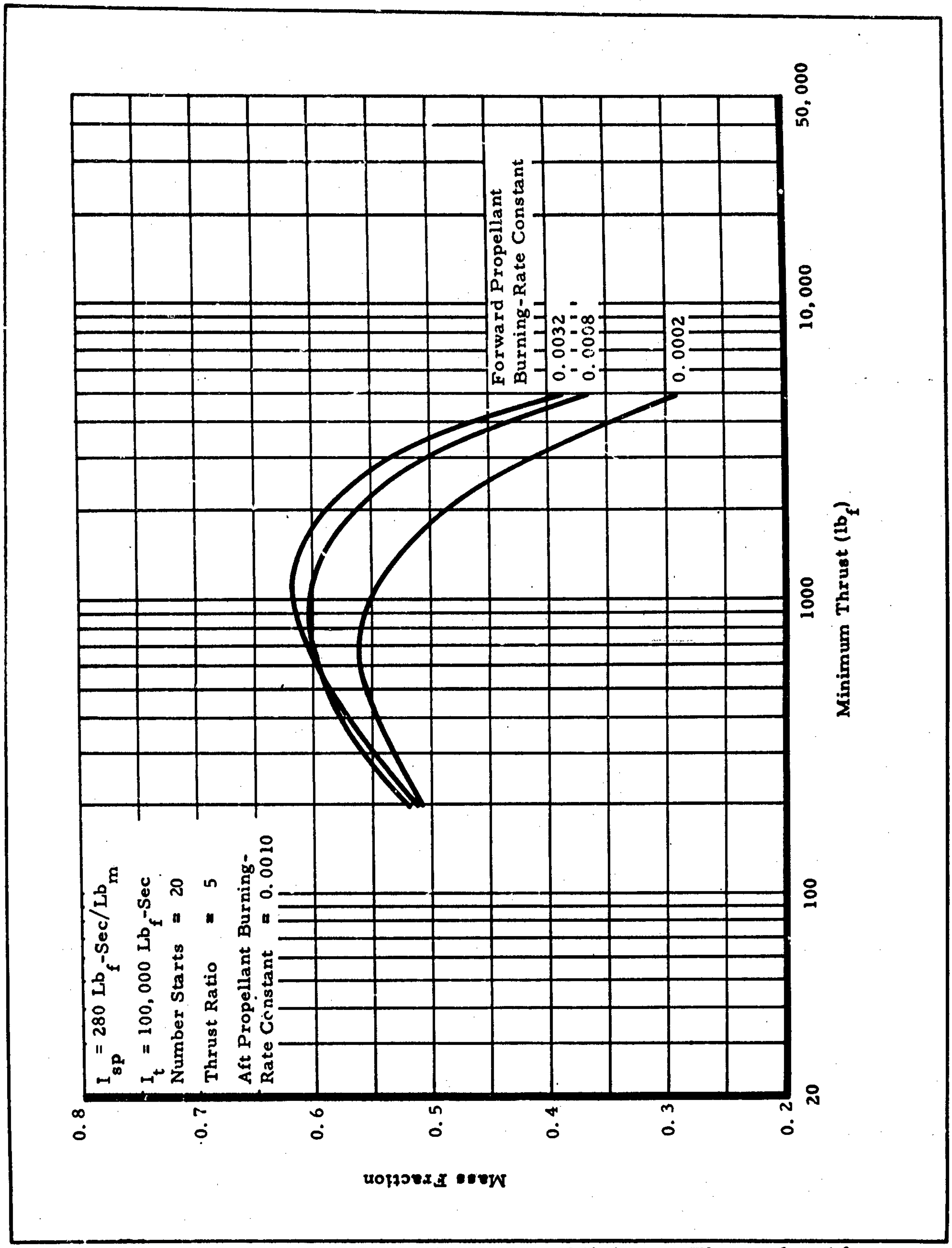


Figure B-39 - Mass Fraction versus Minimum Thrust for Aft Propellant Burning-Rate Constant of 0.0010

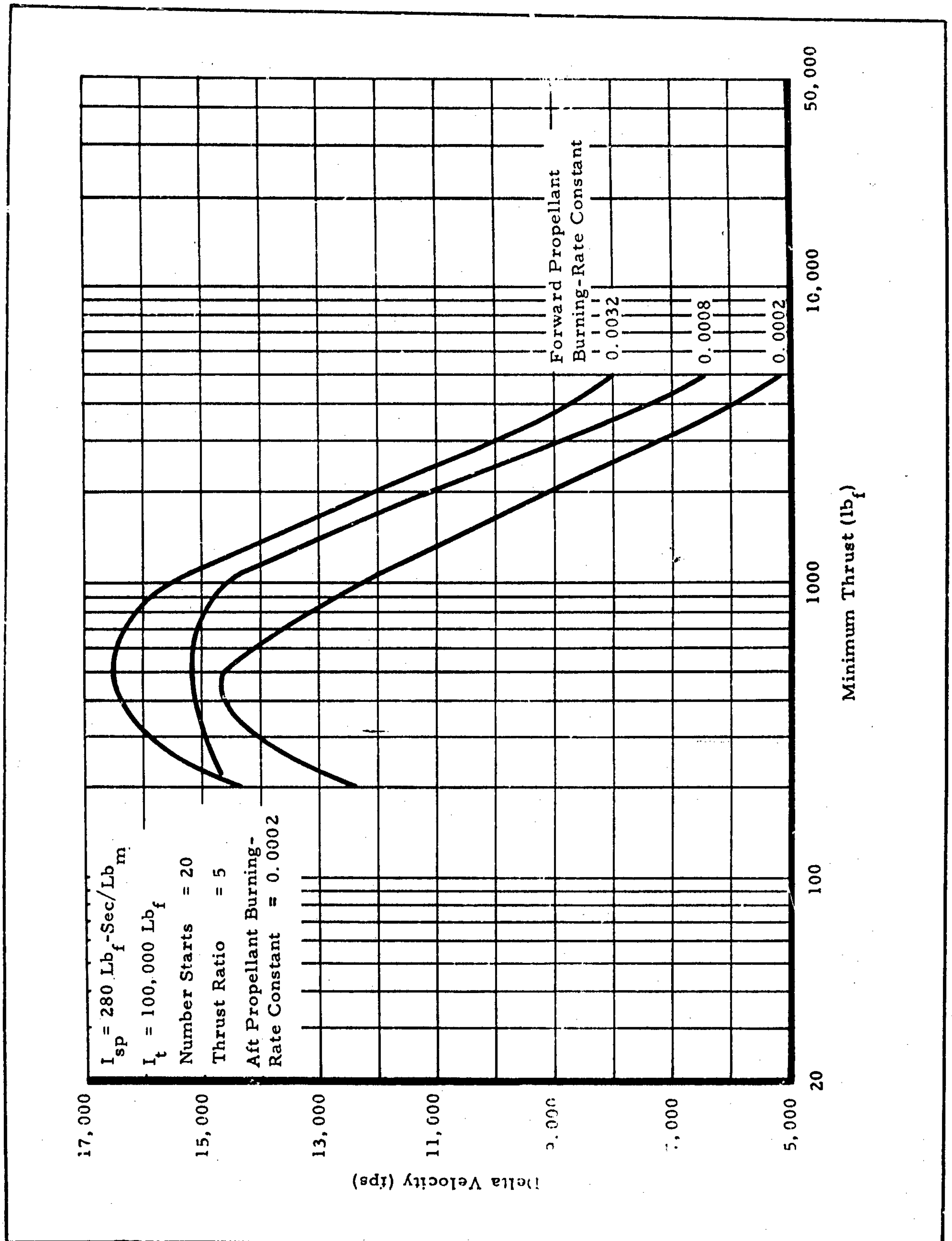


Figure B-40 - Delta Velocity versus Minimum Thrust for Aft Propellant Burning-Rate Constant of 0.0002

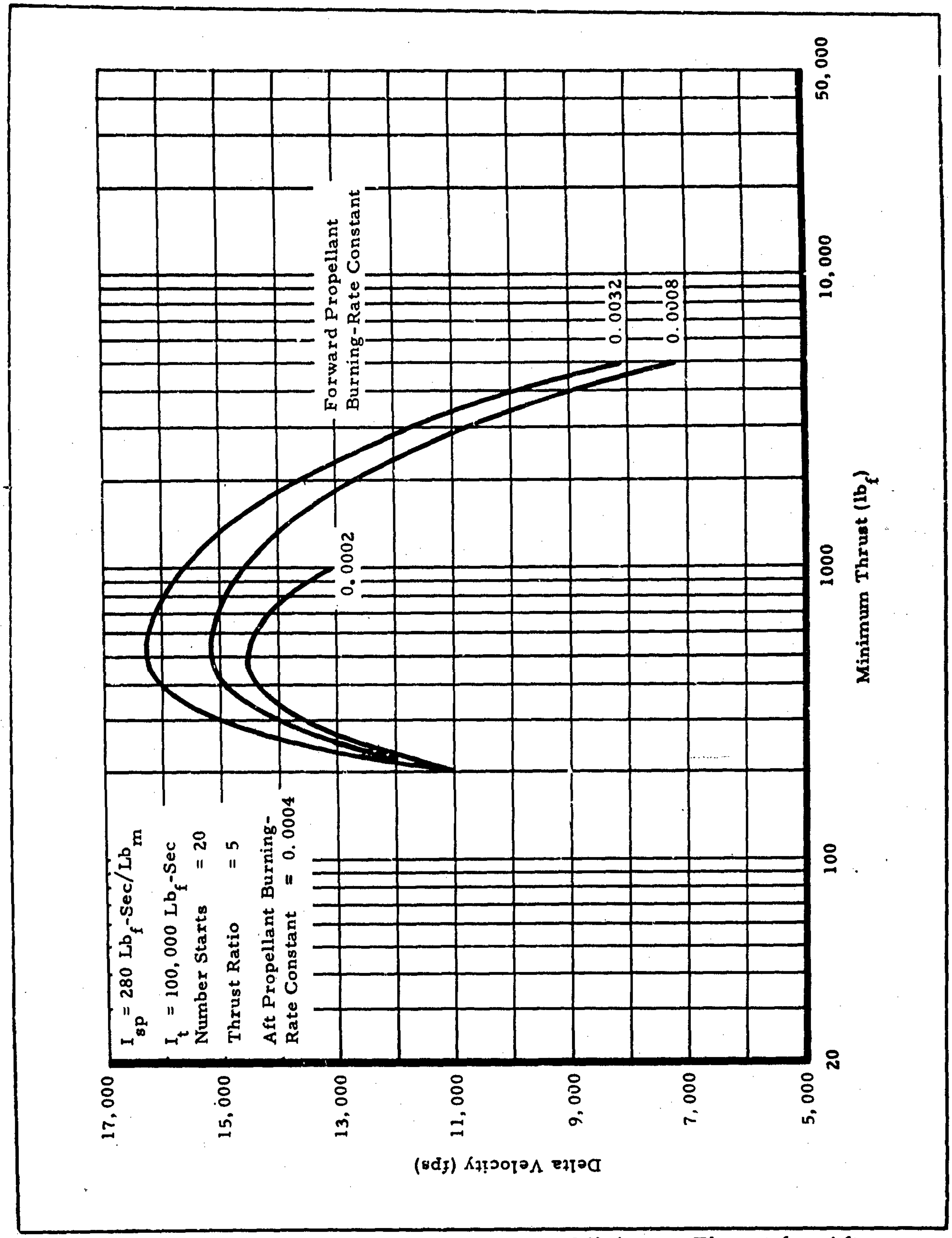


Figure B-41 - Delta Velocity versus Minimum Thrust for Aft Propellant Burning-Rate Constant of 0.0004

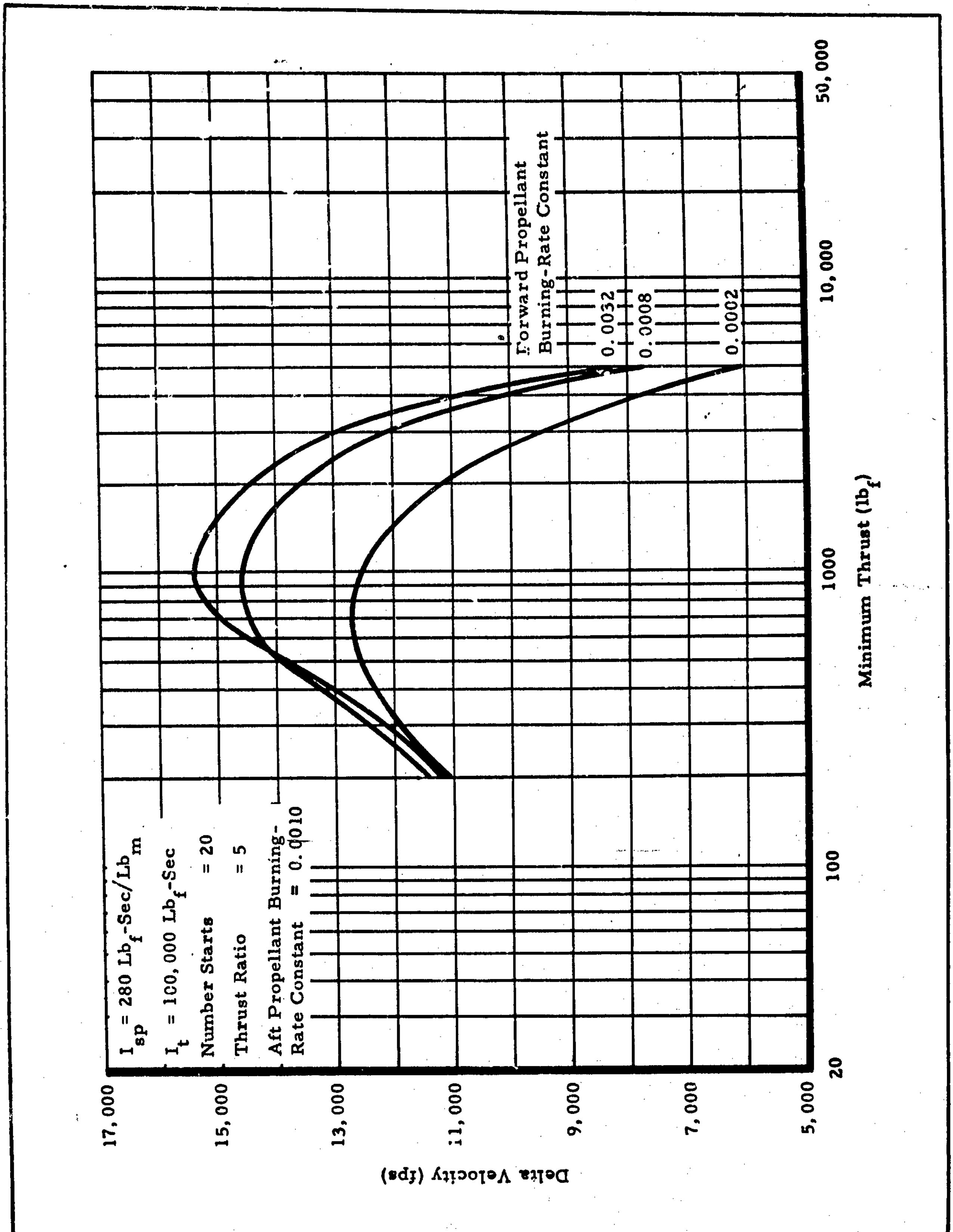


Figure B-42 - Delta Velocity versus Minimum Thrust for Aft Propellant Burning-Rate Constant of 0.0010

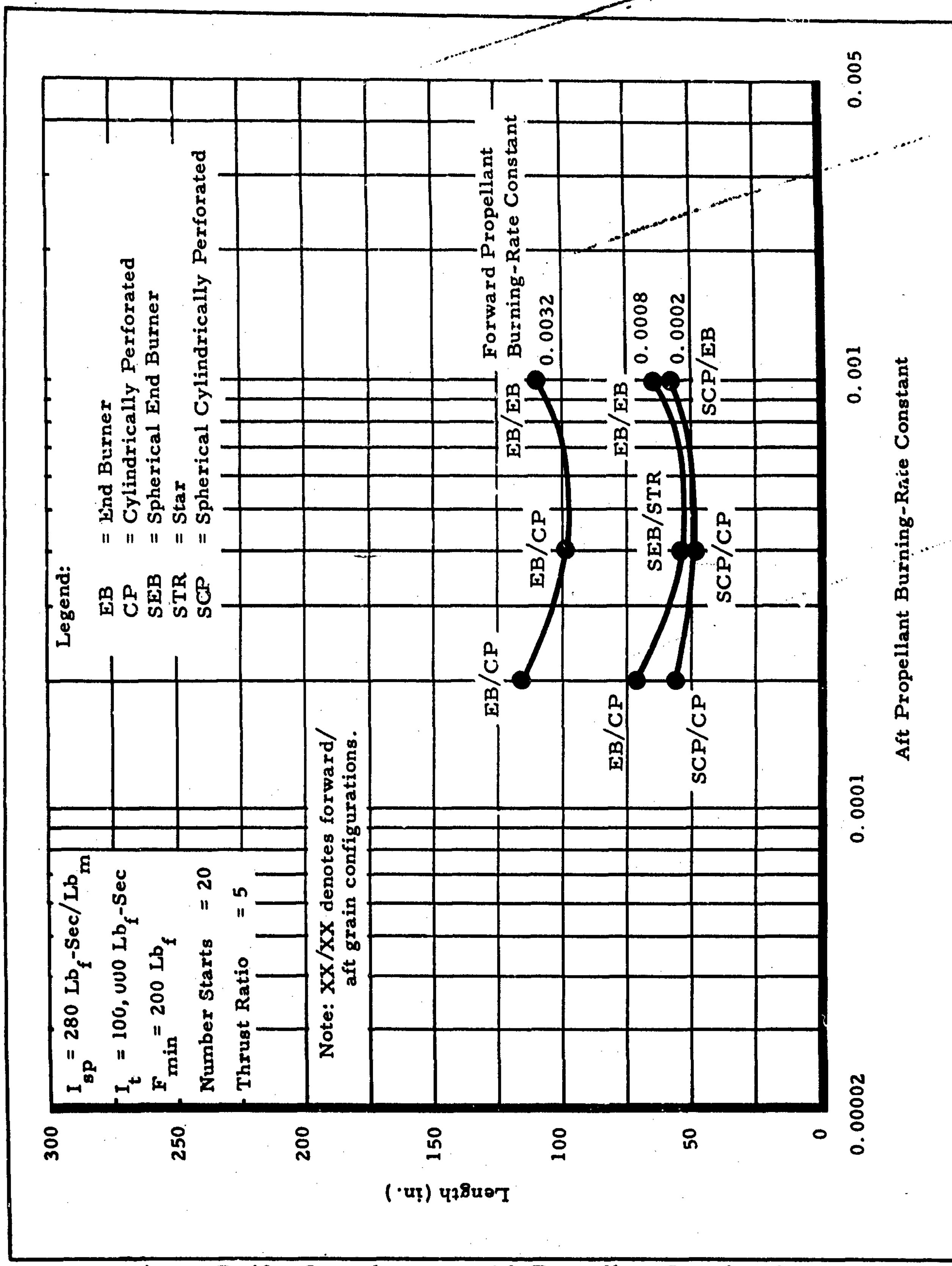


Figure B-43 - Length versus Aft Propellant Burning-Rate Constant for F_{min} = 200 Lb_f

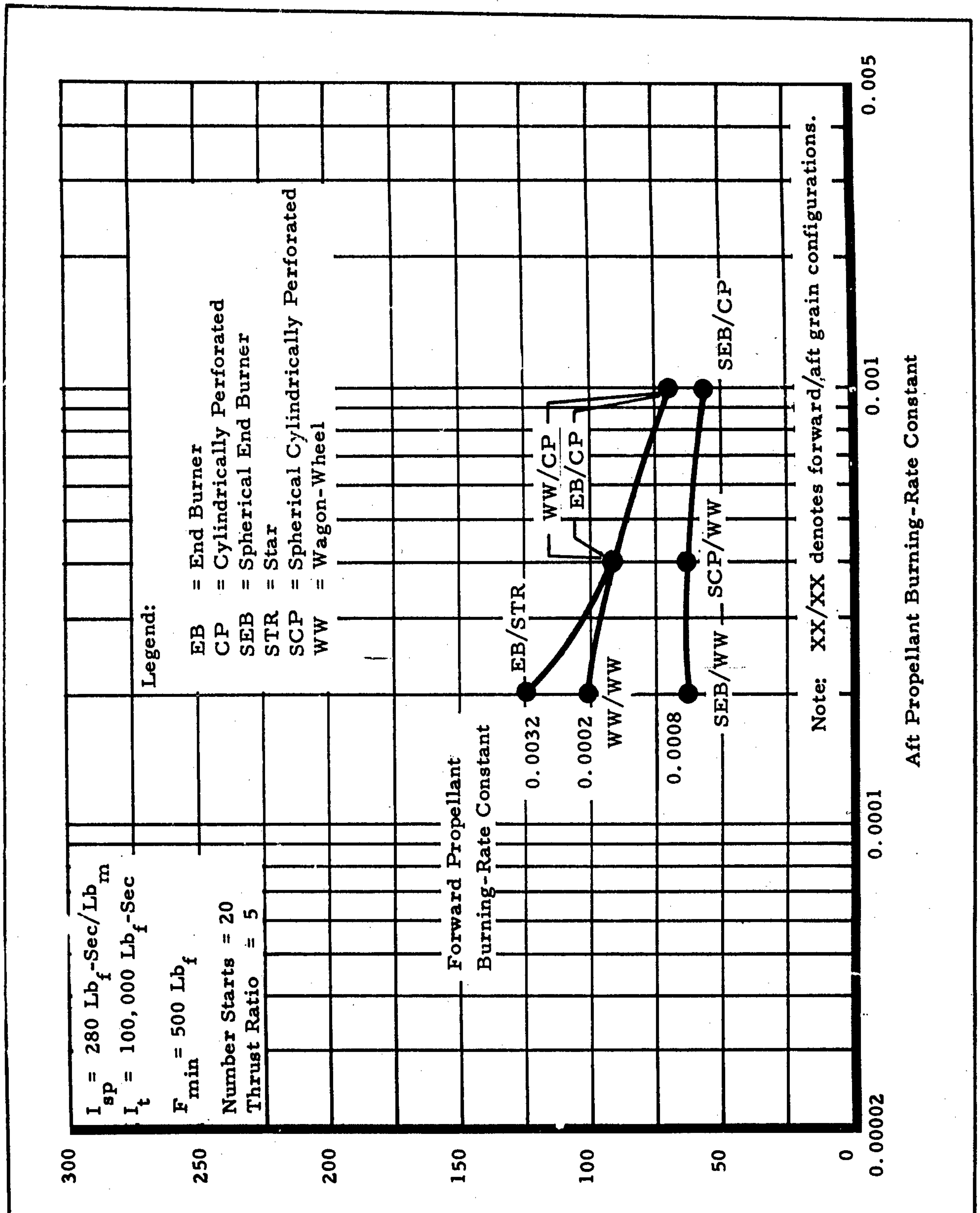


Figure B-44 - Length versus Aft Propellant Burning-Rate Constant for F_{min} = 500 Lb_f

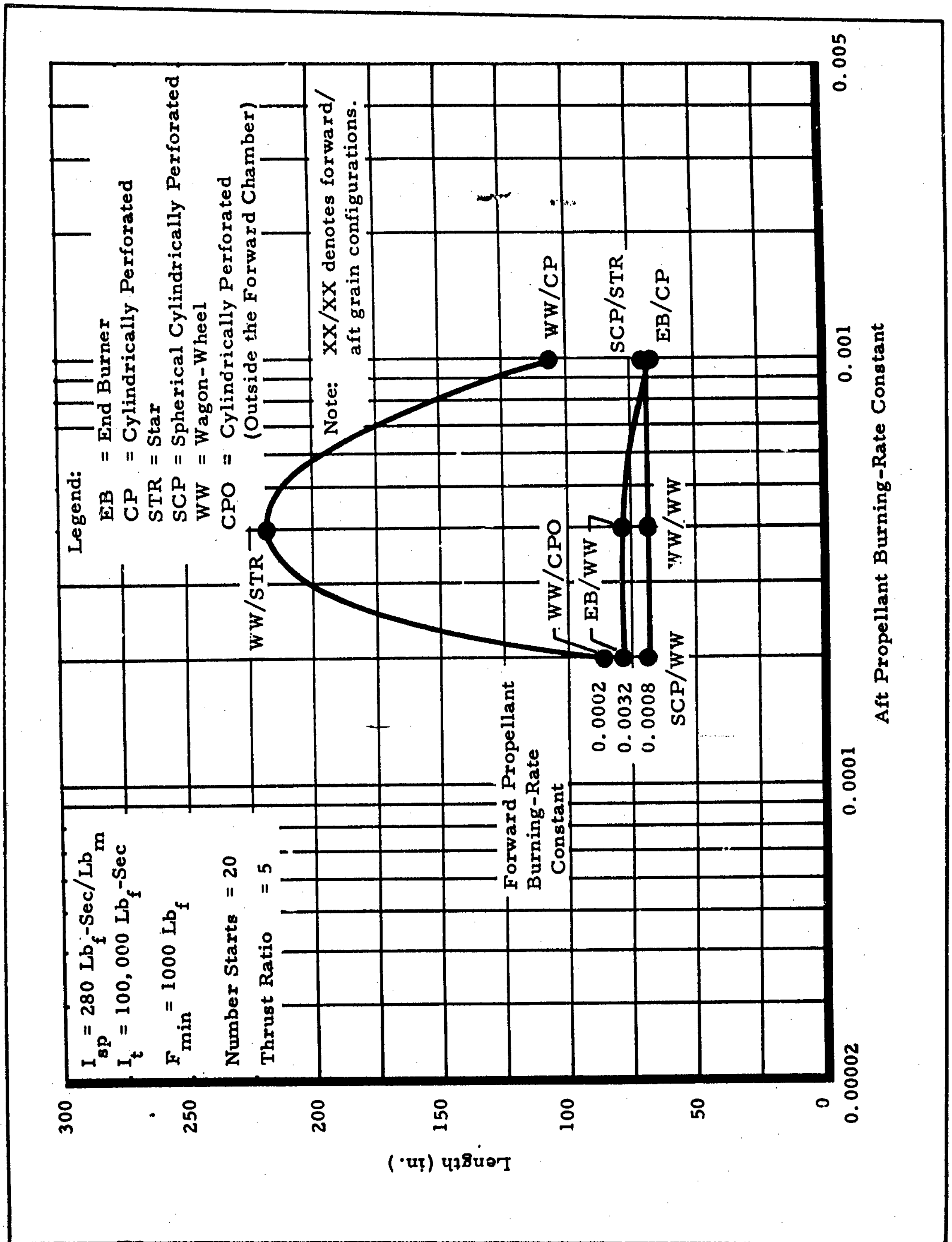


Figure B-45 - Length versus Aft Propellant Burning-Rate Constant for F_{min} = 1000 Lb_f

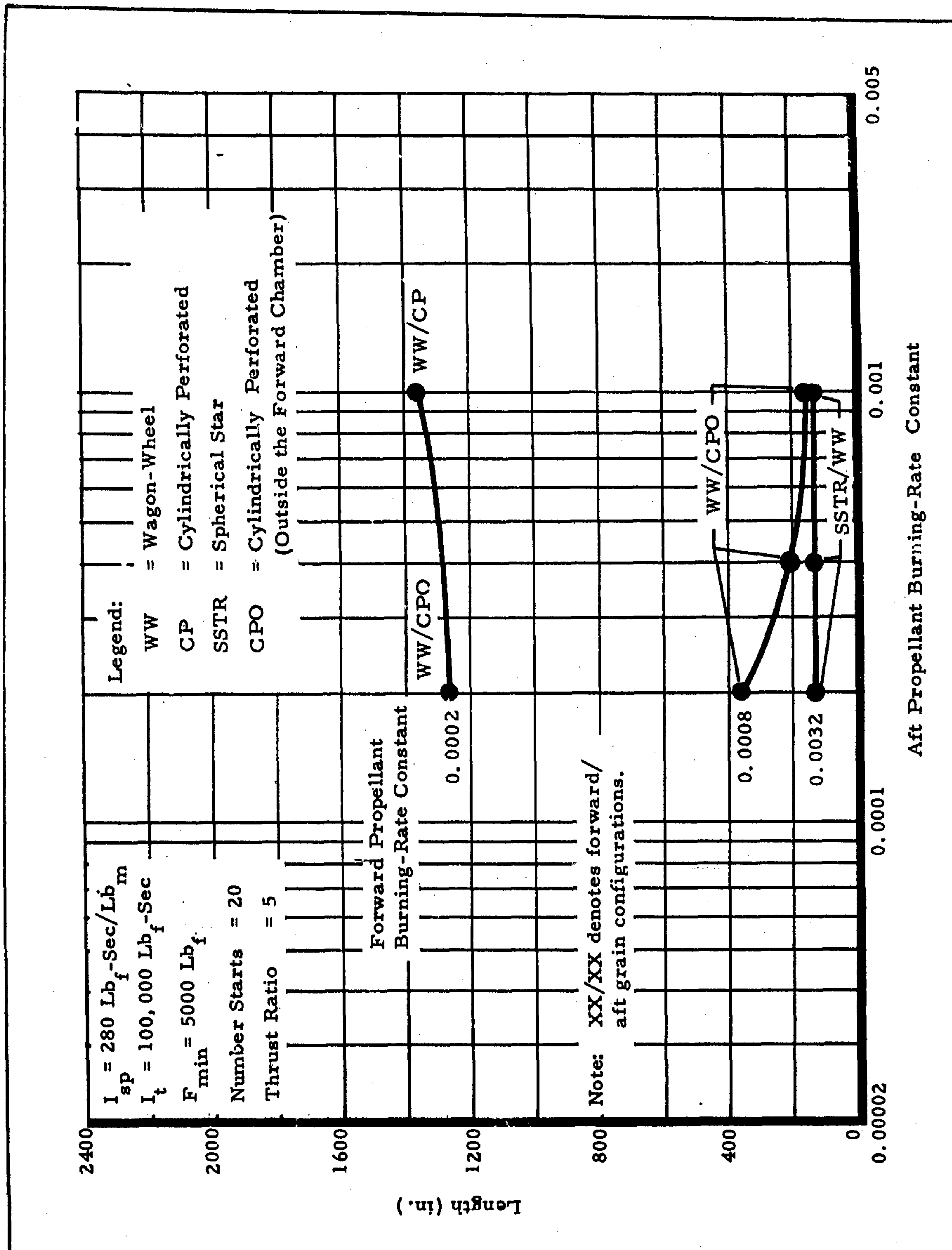


Figure B-46 - Length versus Aft Propellant Burning-Rate Constant for F_{min} = 5000 Lb_f

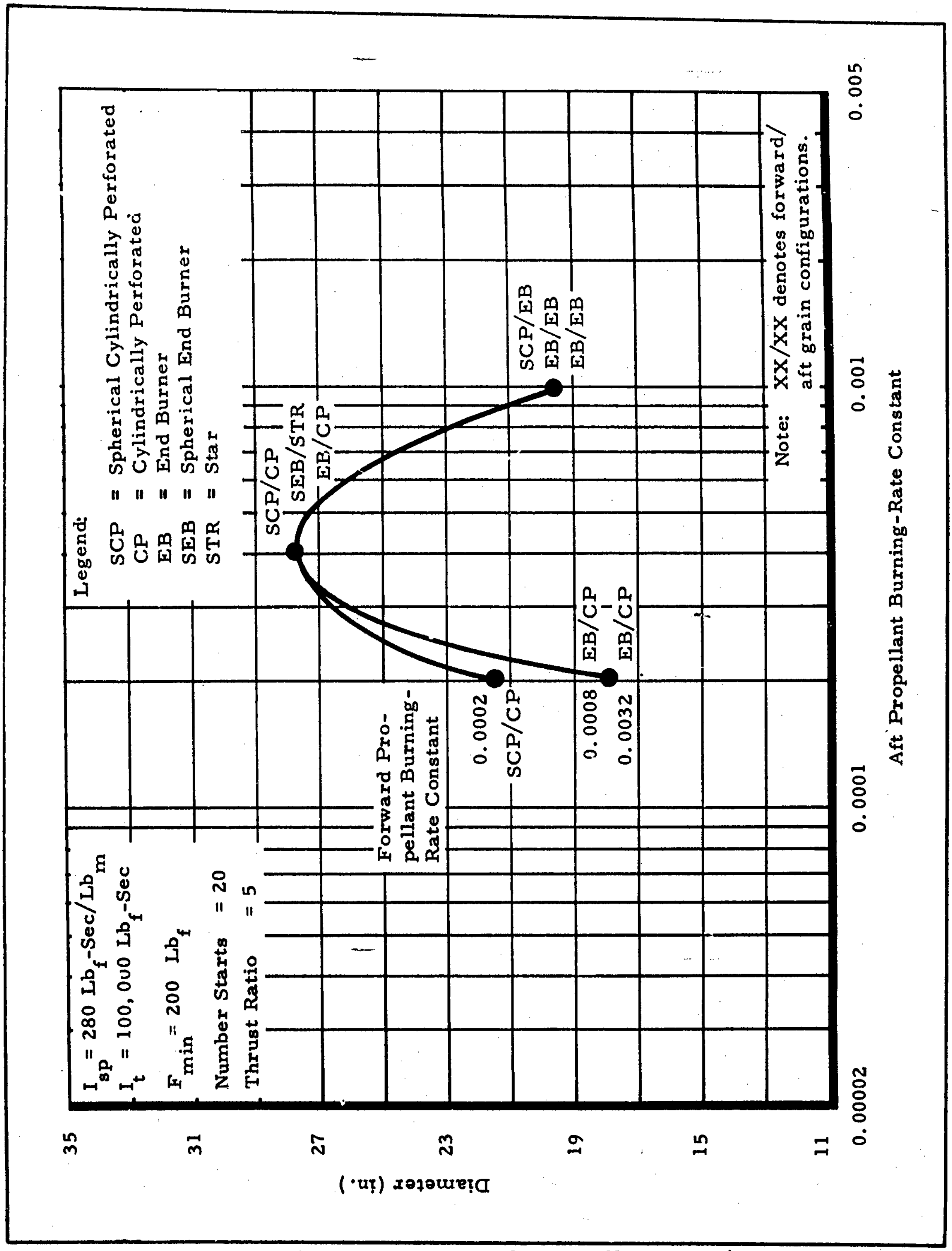


Figure B-47 - Diameter versus Aft Propellant Burning-Rate Constant for F_{min} = 200 Lb_f

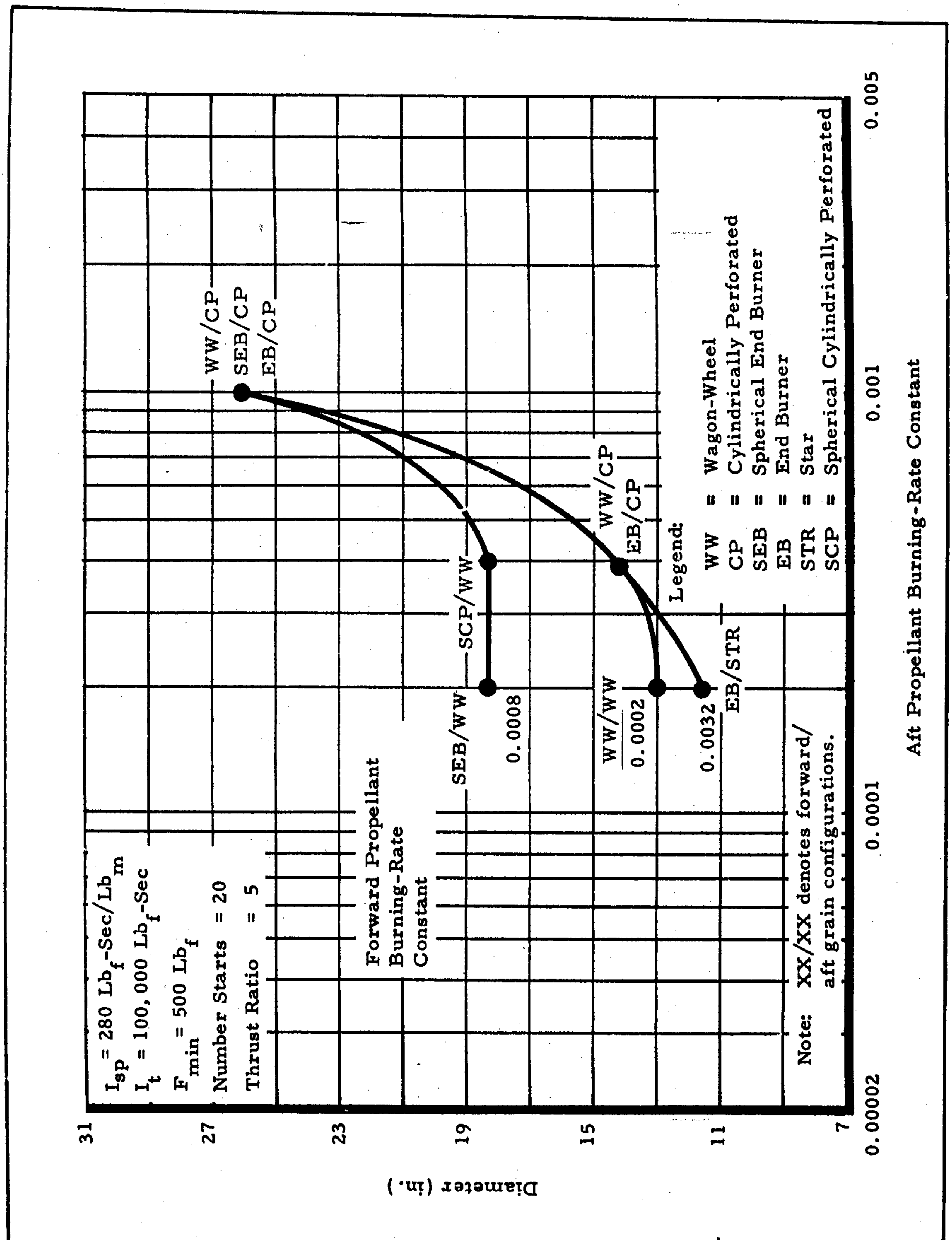


Figure B-48 - Diameter versus Aft Propellant Burning-Rate Constant for F_{min} = 500 Lb_f

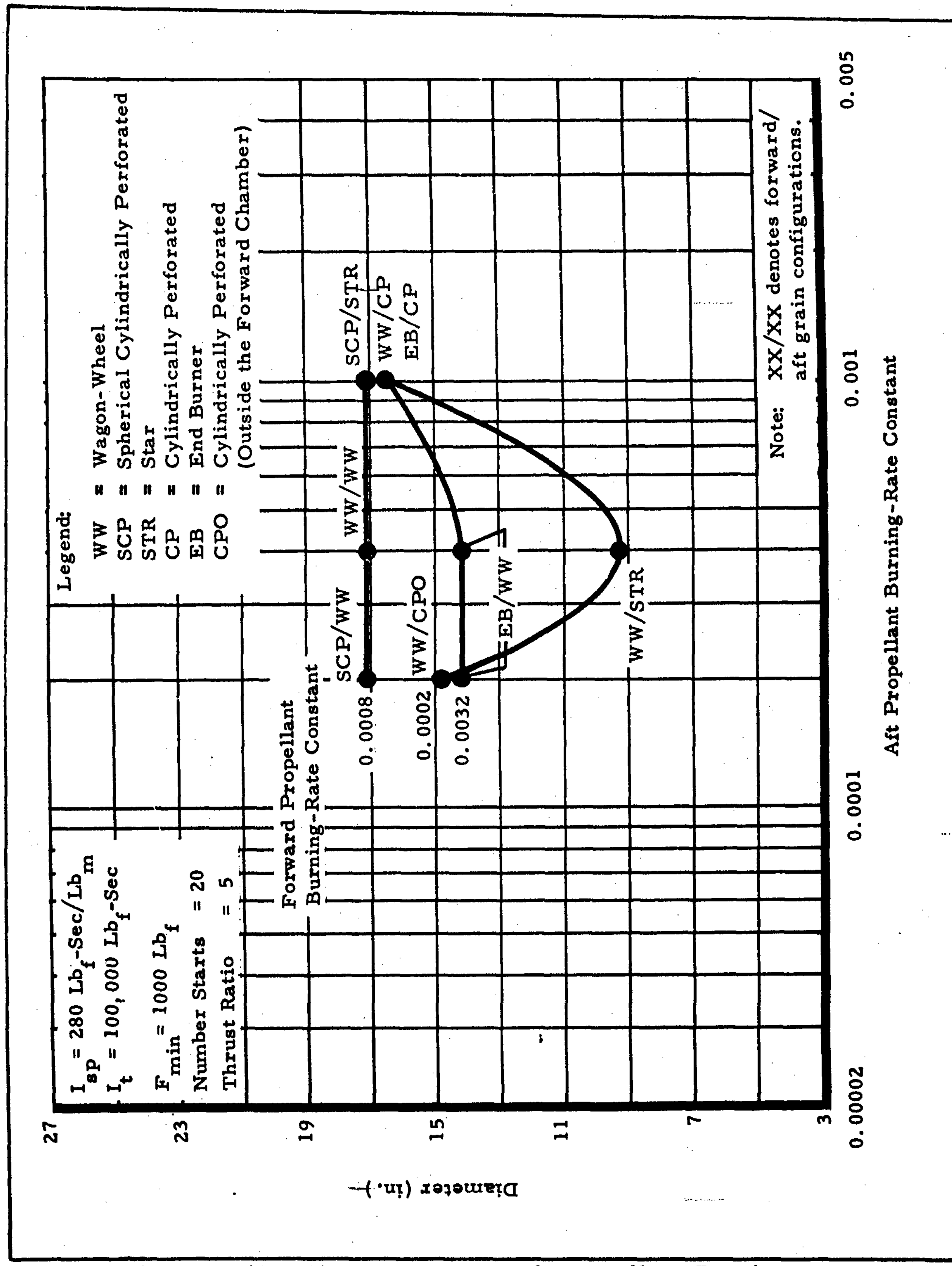


Figure B-49 - Diameter versus Aft Propellant Burning-Rate Constant for F_{min} = 1000 Lb_f

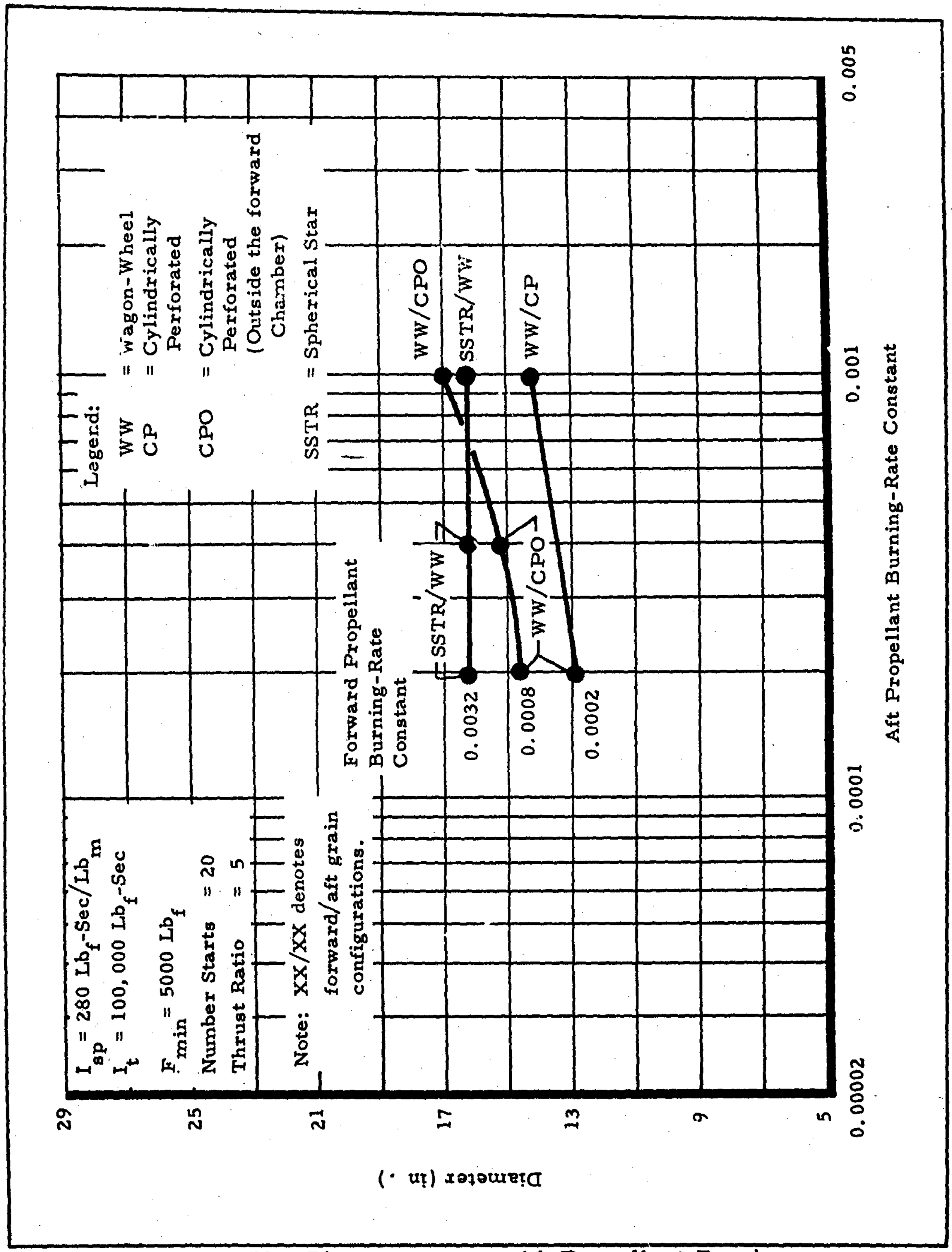


Figure B-50 - Diameter versus Aft Propellant Burning-Rate Constant for F_{min} = 5000 Lb_f

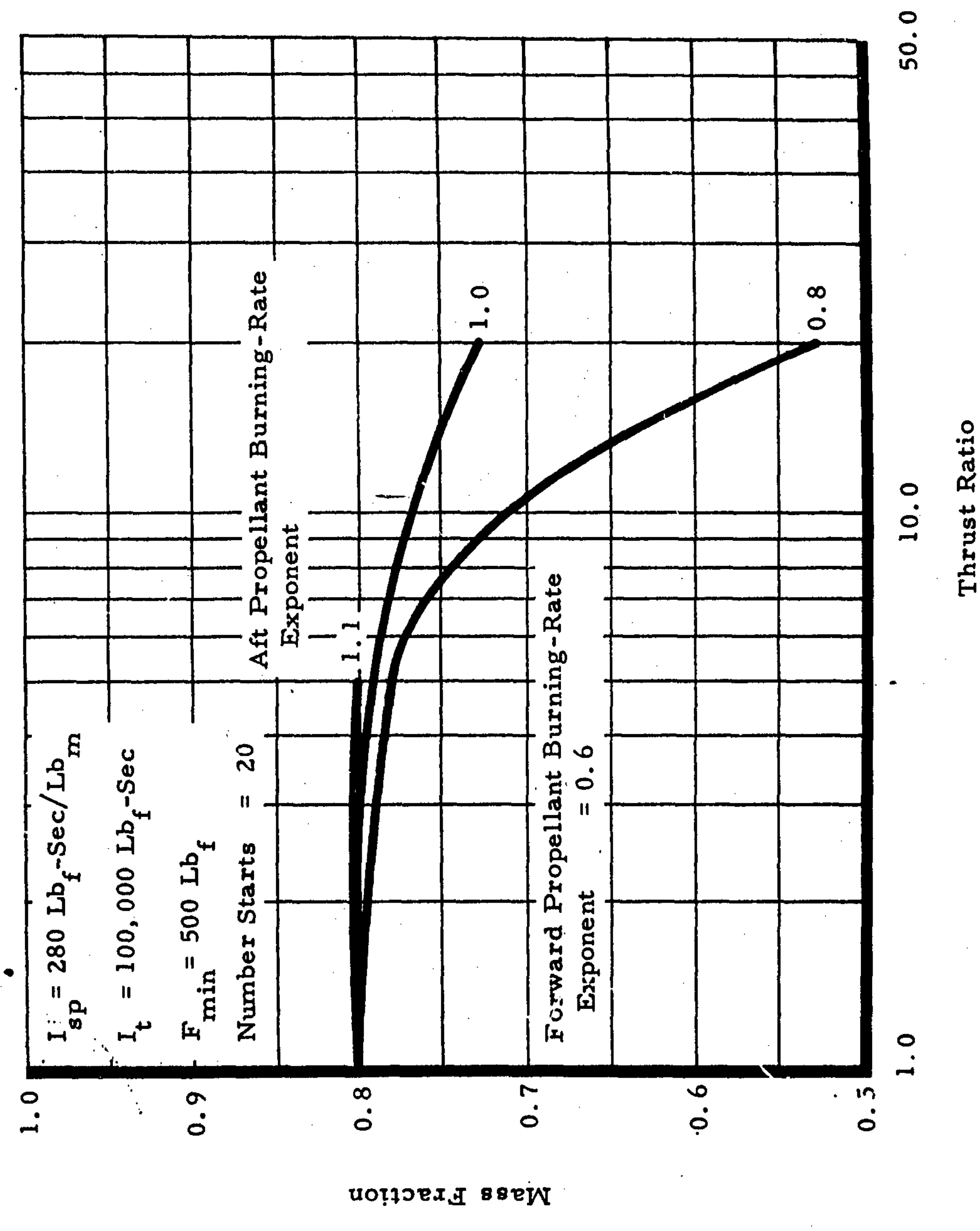


Figure B-51 - Mass Fraction versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.6

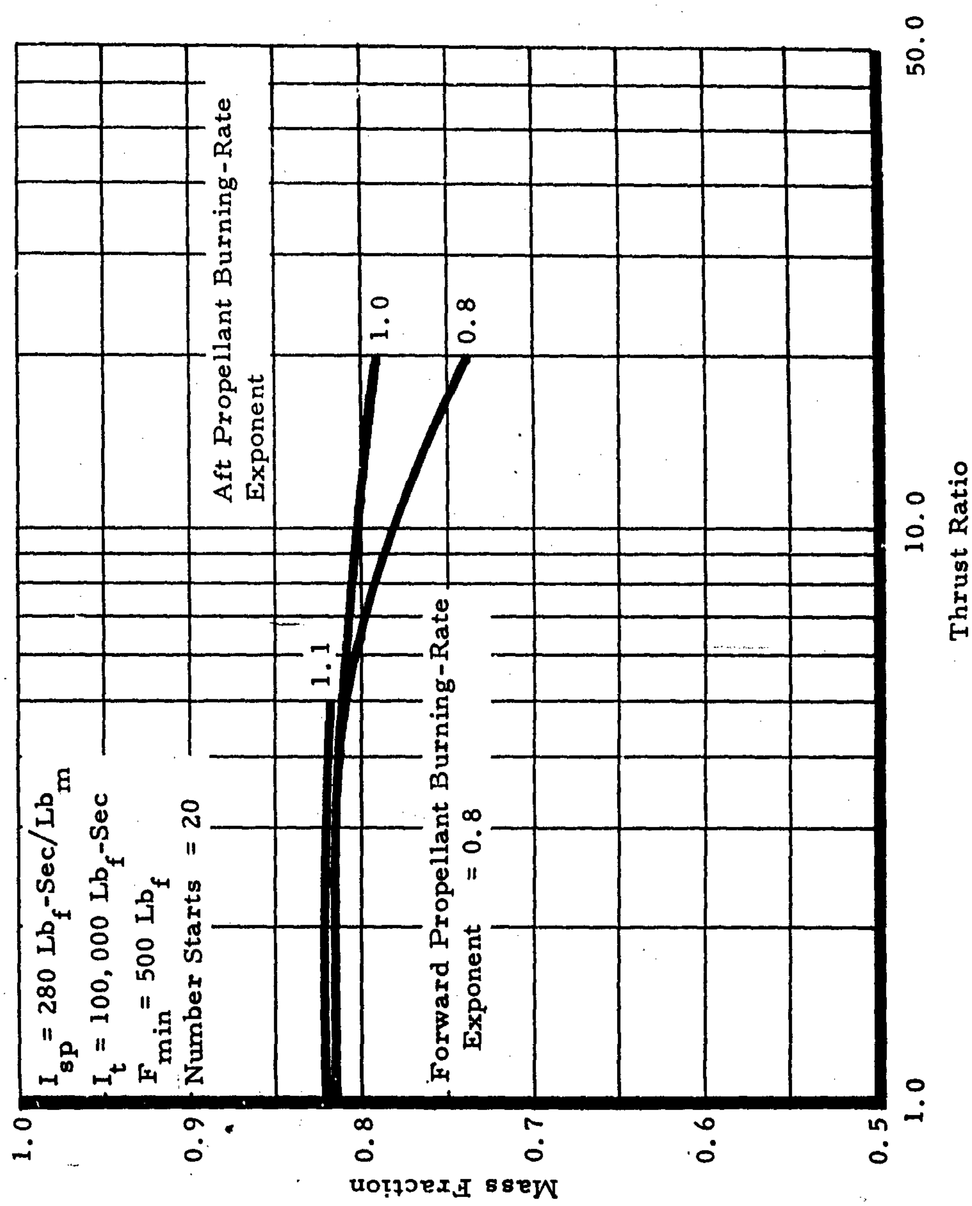


Figure B-52 - Mass Fraction versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.8

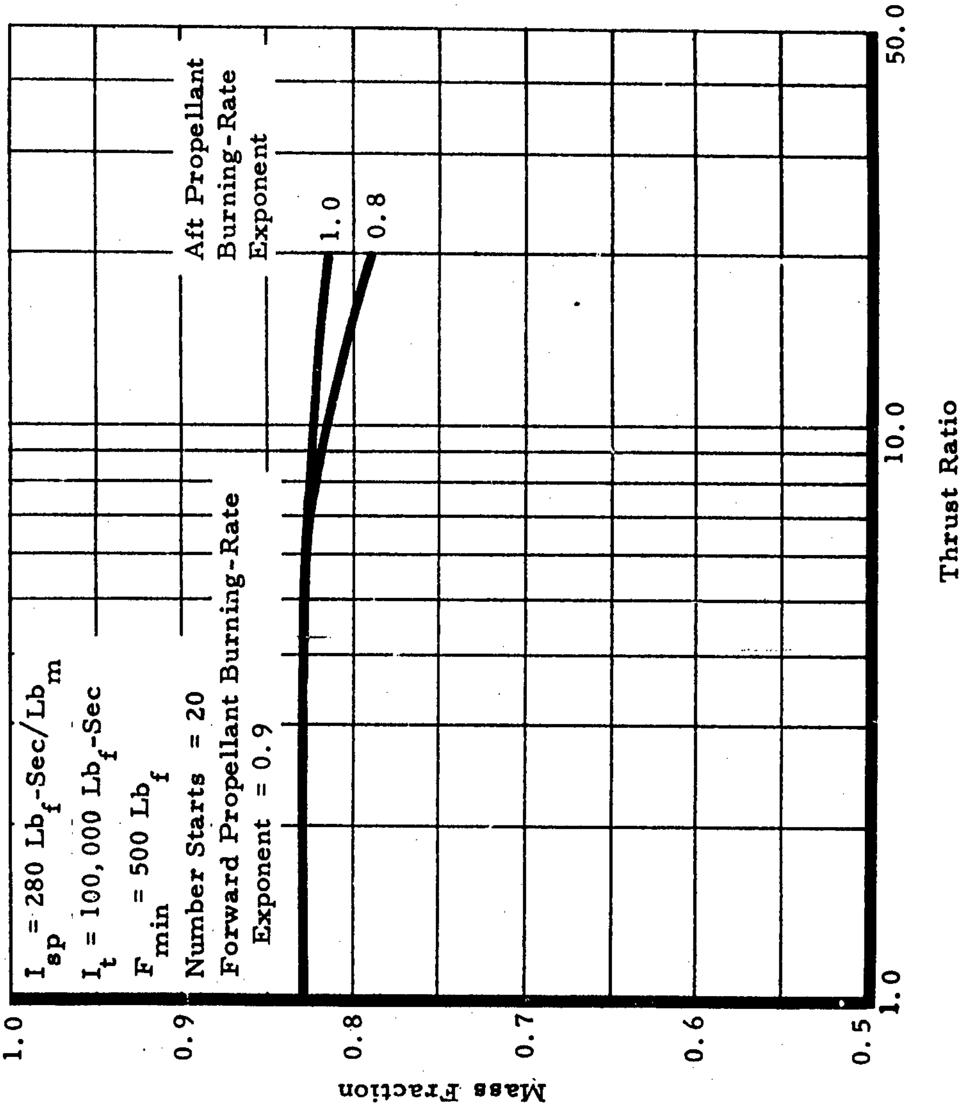


Figure B-53 - Mass Fraction versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.9

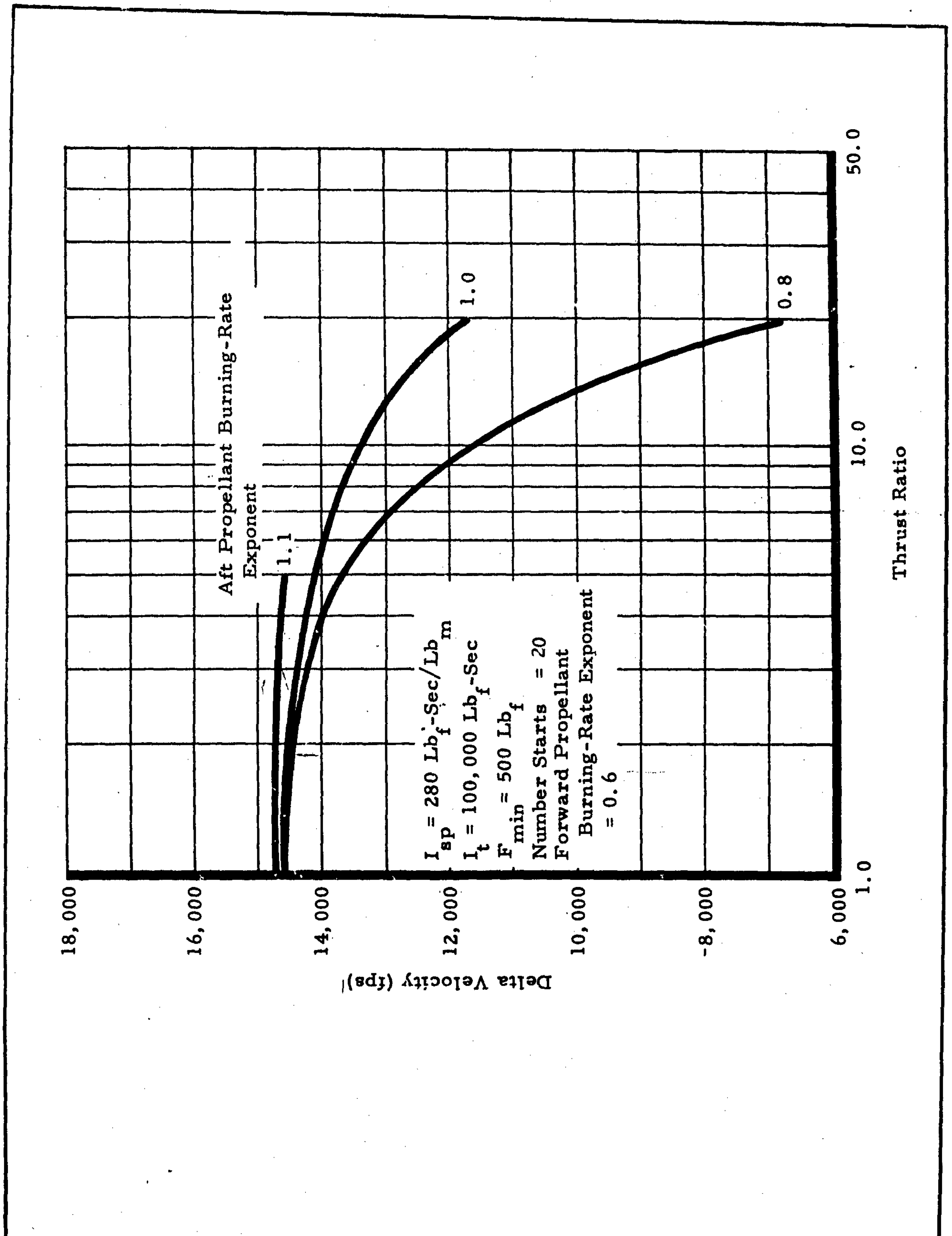


Figure B-54 - Delta Velocity versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.6

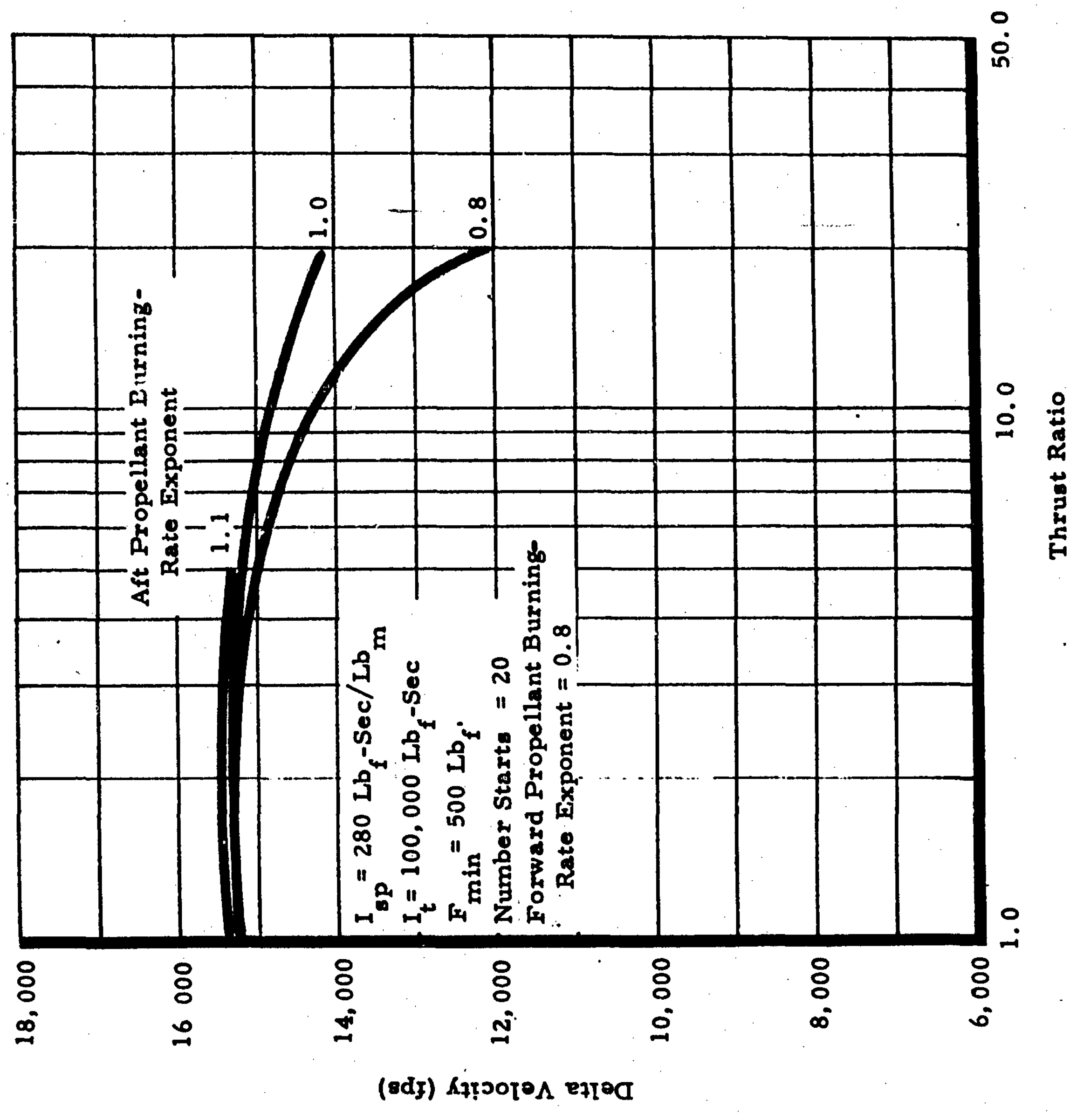


Figure B-55 - Delta Velocity versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.8

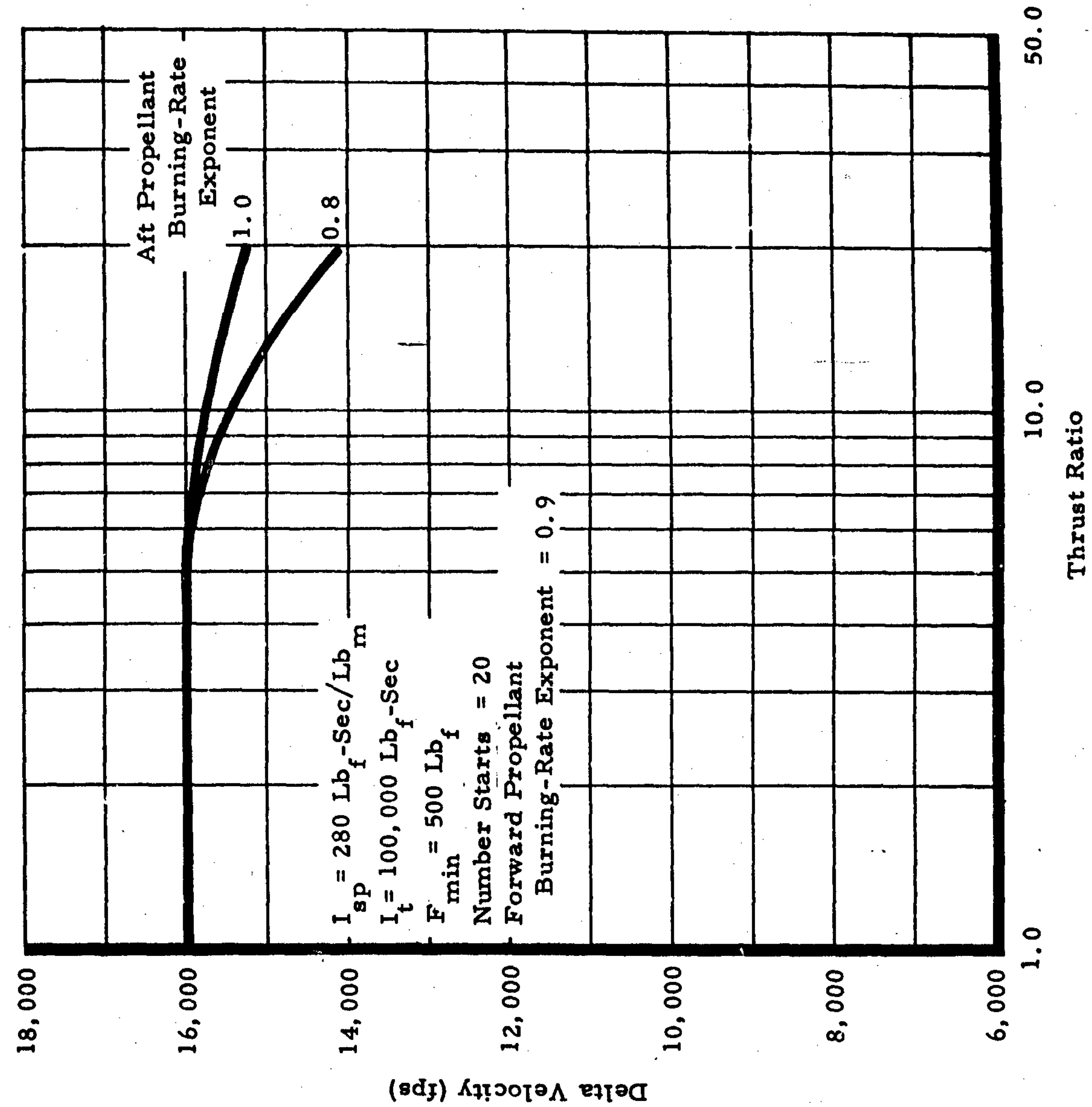


Figure B-56 - Delta Velocity versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.9

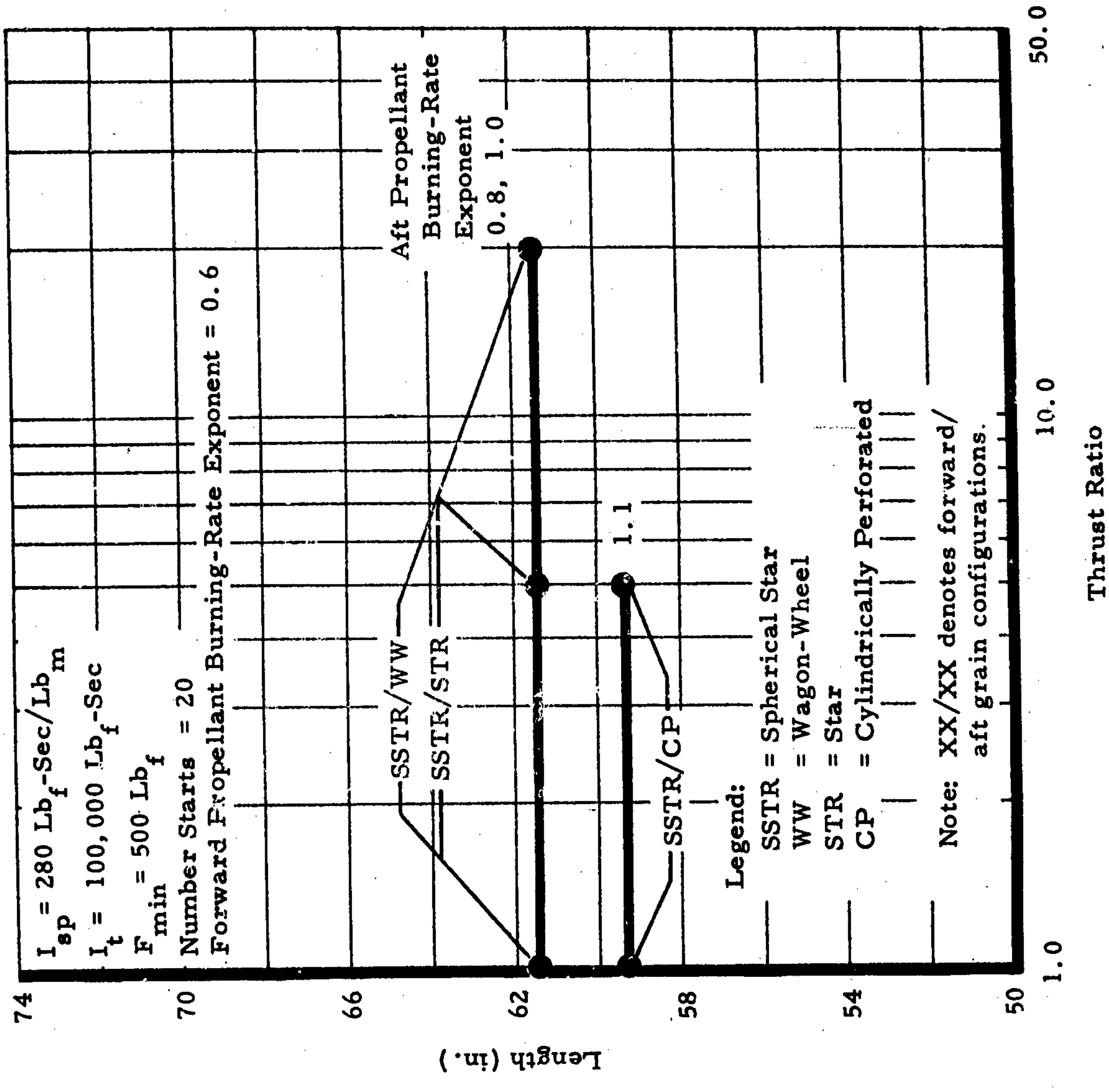


Figure B-57 - Length versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.6

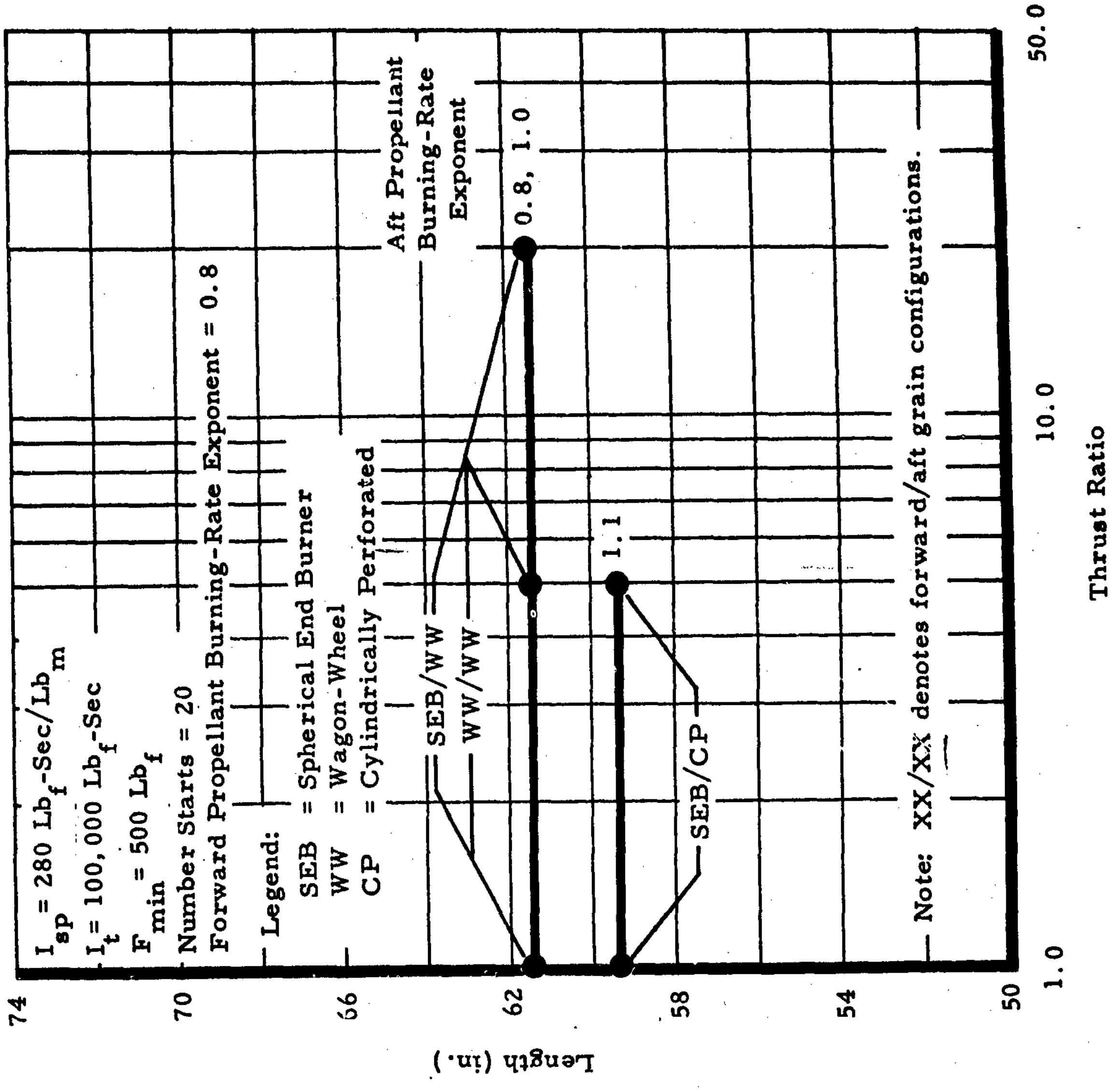


Figure B-58 - Length versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.8

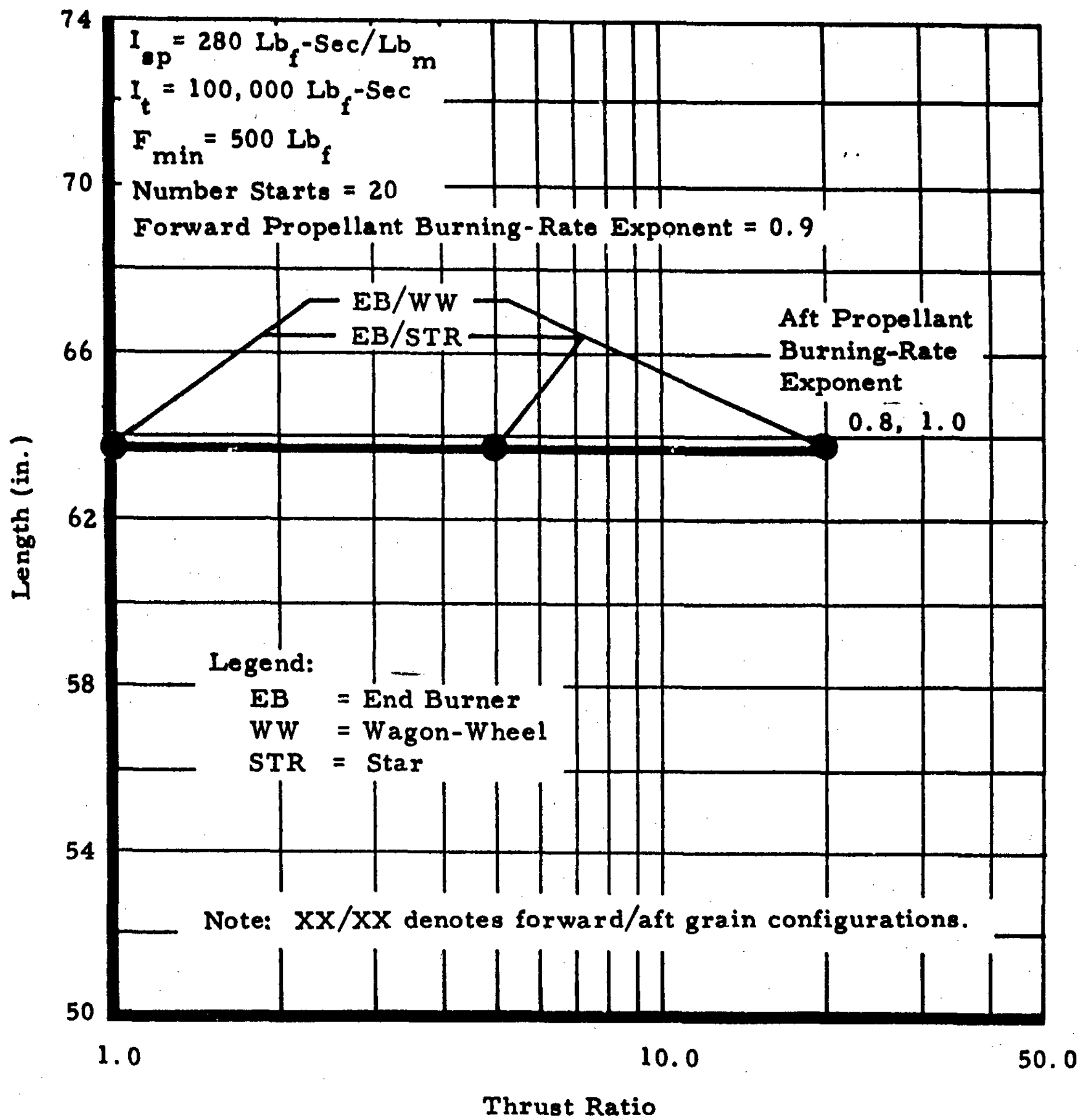


Figure B-59 - Length versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.9

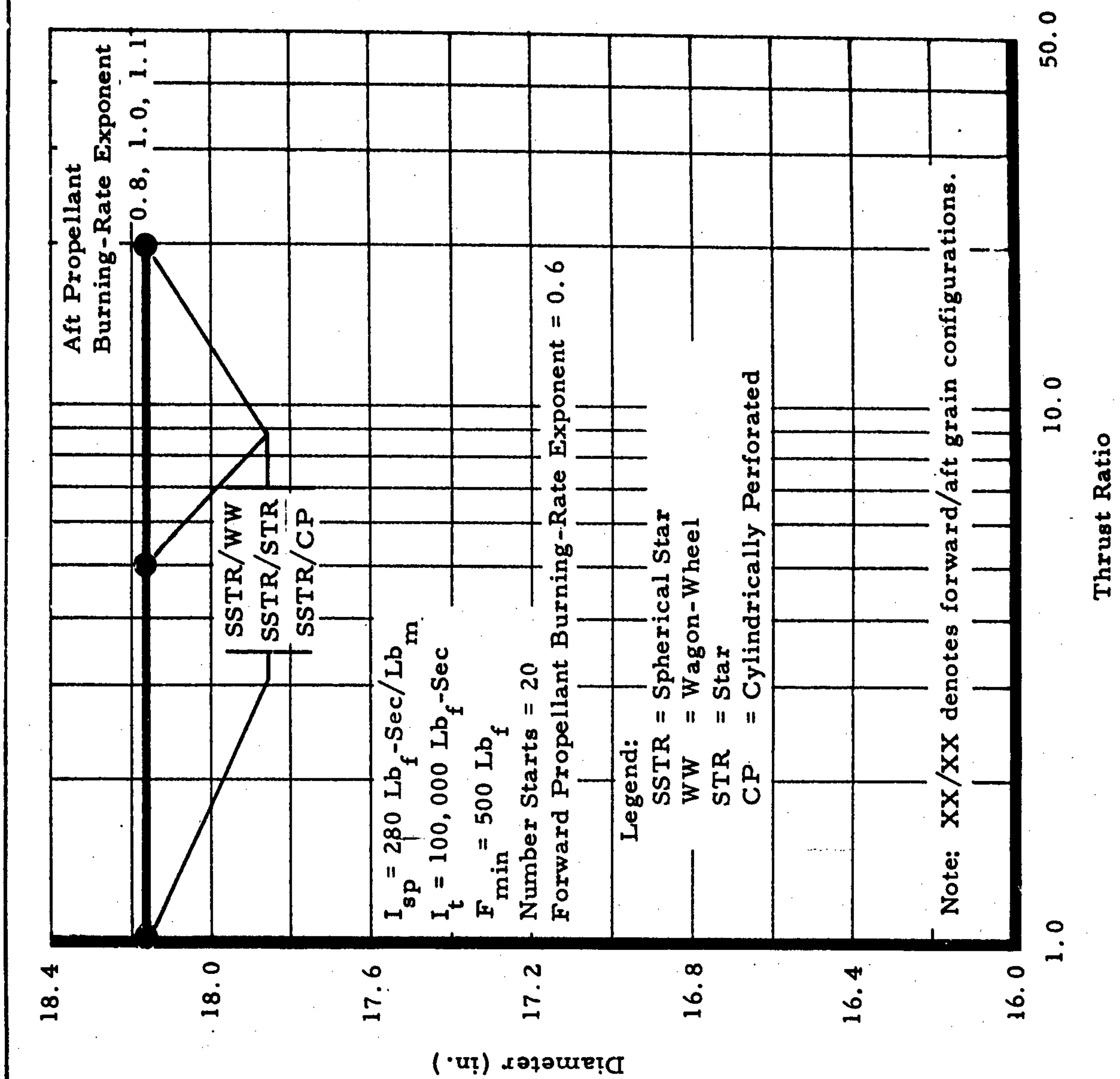


Figure B-60 - Diameter versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.6

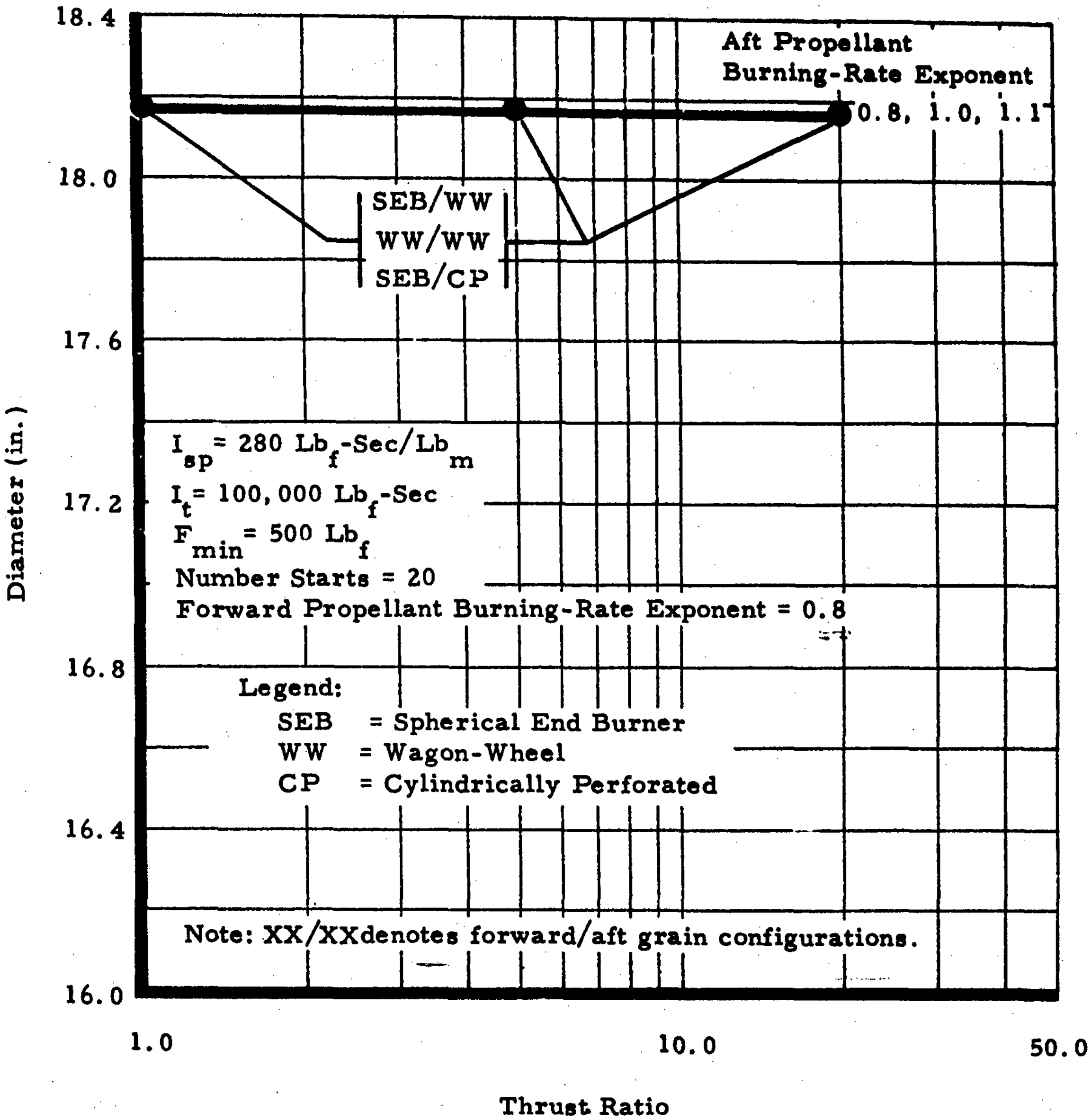
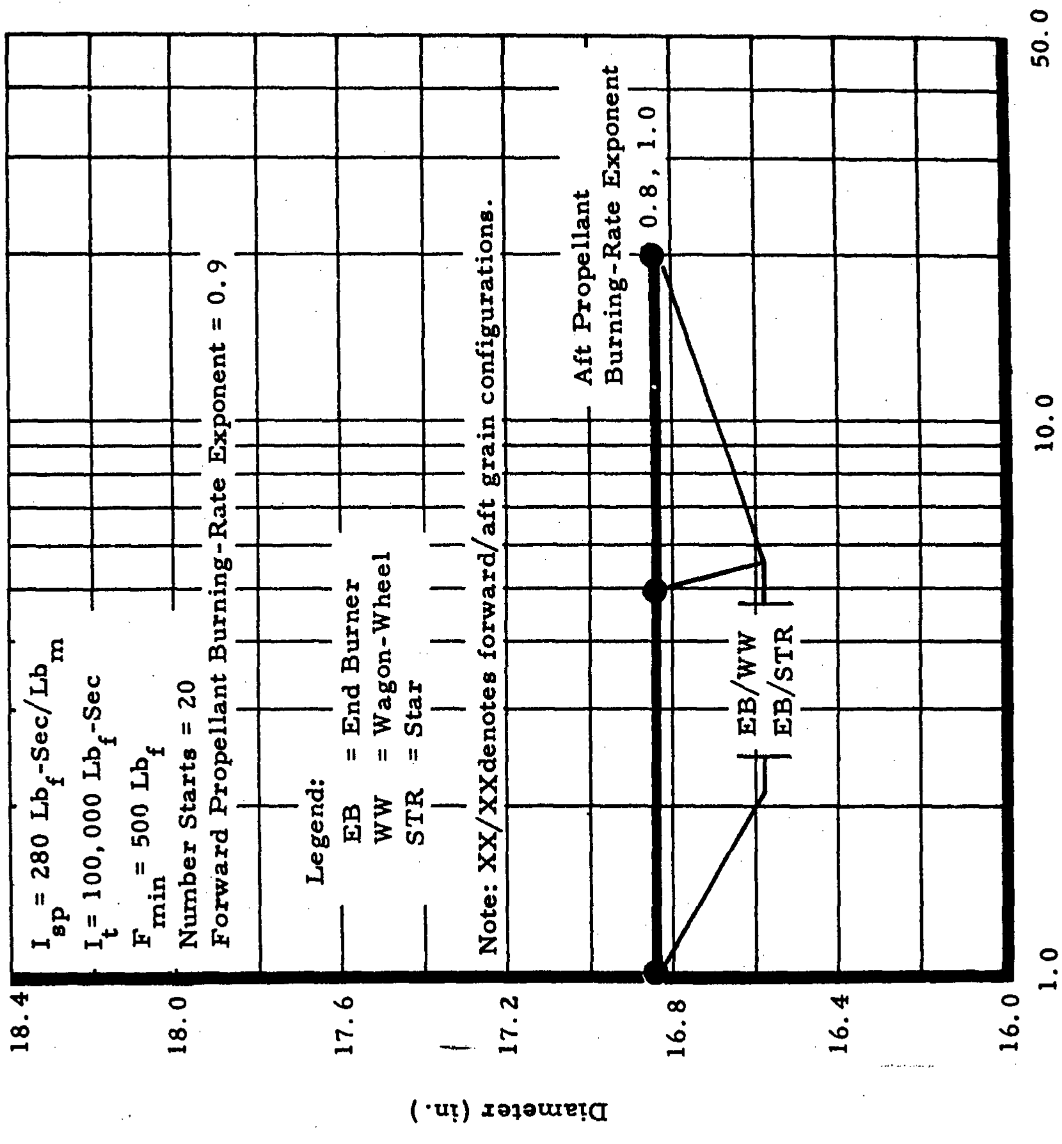


Figure B-61 - Diameter versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.8



'igure B-62 - Diameter versus Thrust Ratio for Forward Propellant Burning-Rate Exponent of 0.9

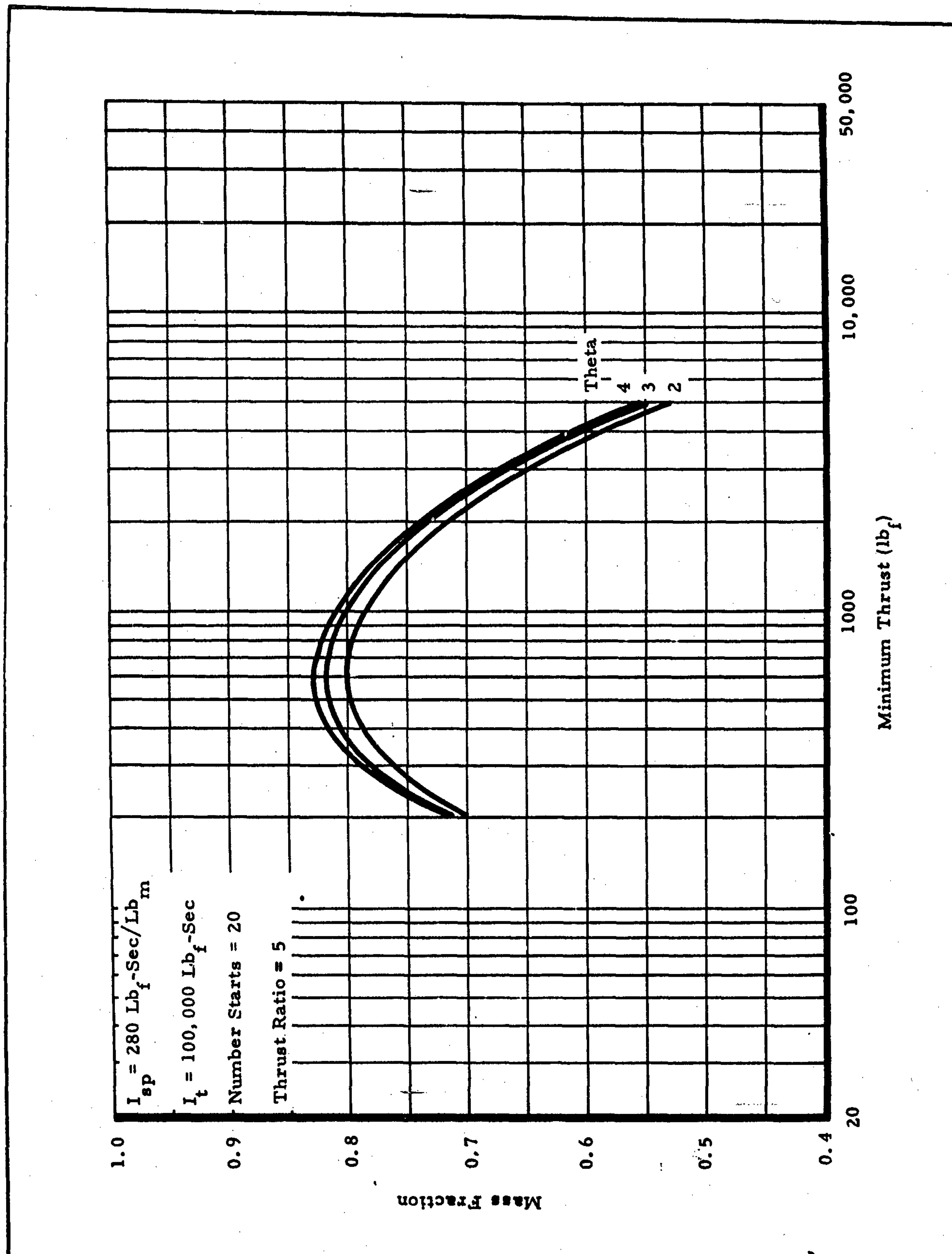


Figure B-63 - Mass Fraction versus Minimum Thrust for Theta Values of 2, 3, and 4

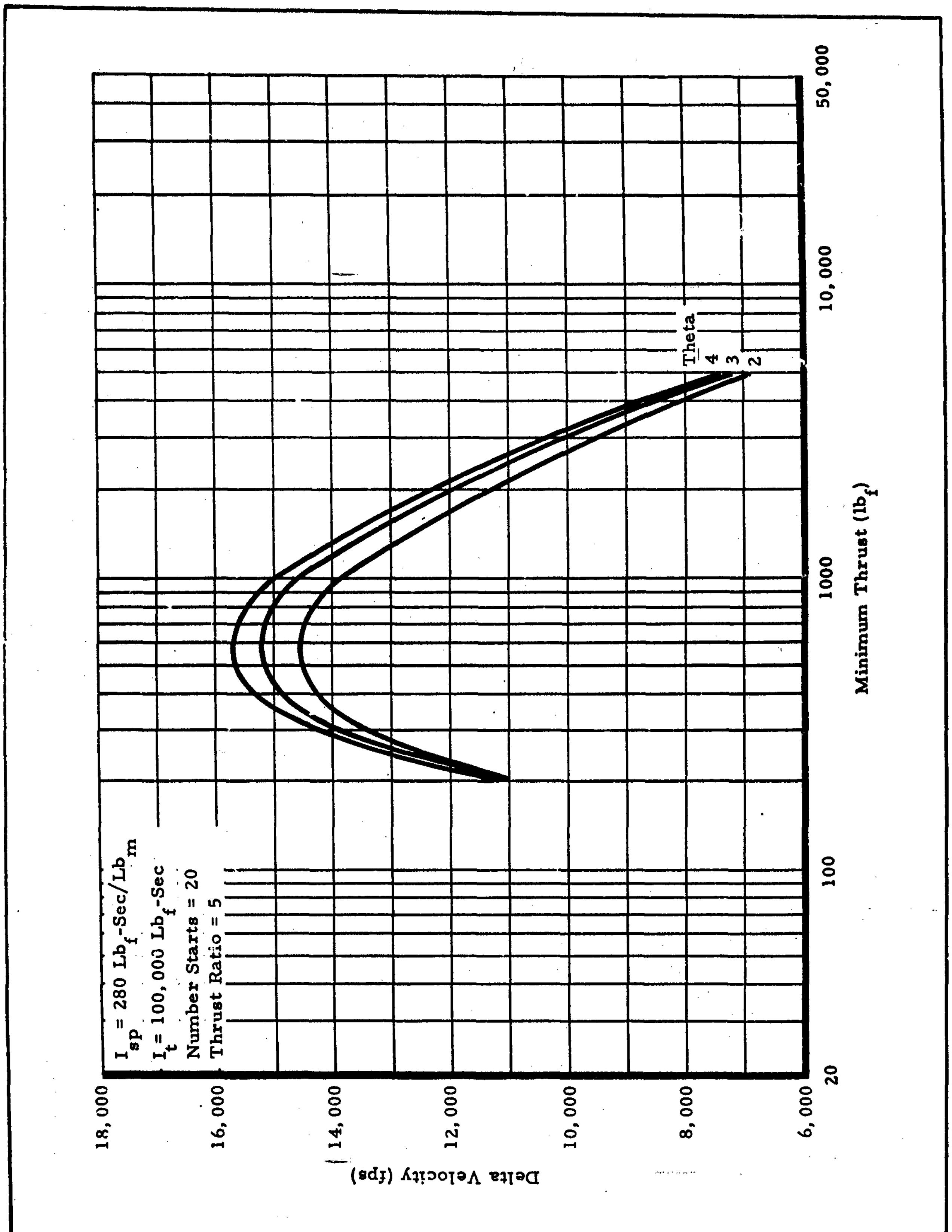


Figure B-64 - Delta Velocity versus Minimum Thrust for Theta Values of 2, 3, and 4

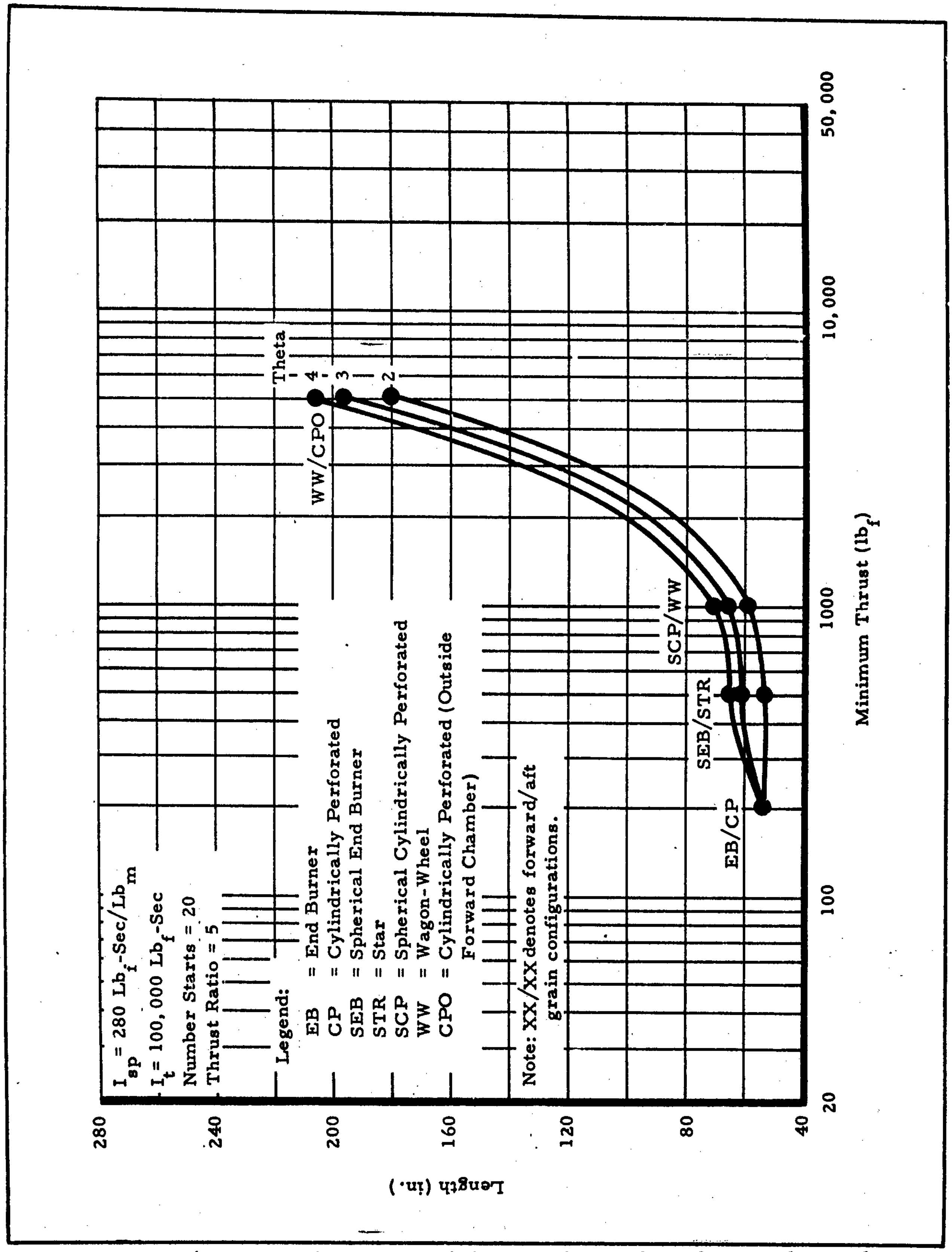


Figure B-65 - Length versus Minimum Thrust for Theta Values of 2, 3, and 4

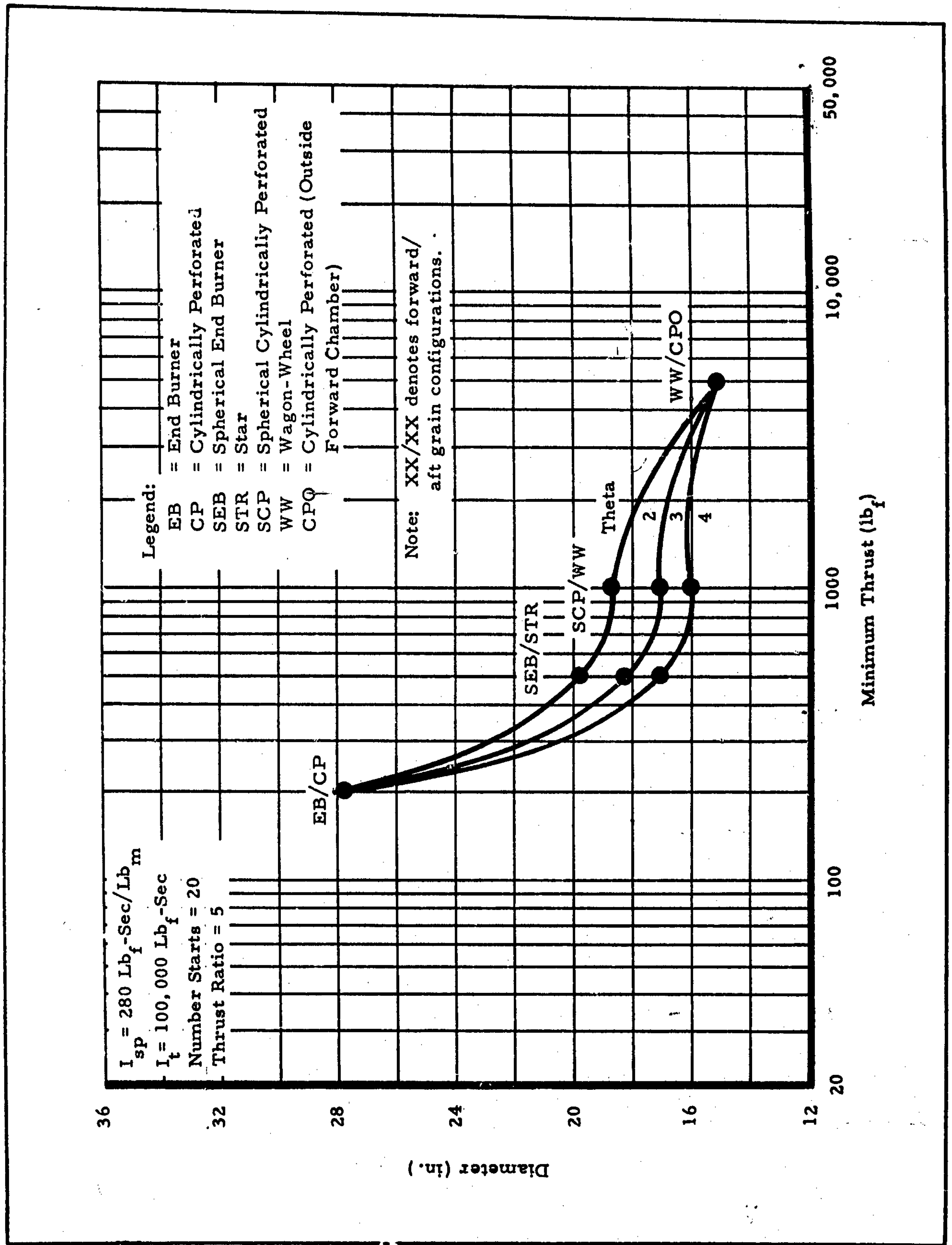


Figure B-66 - Diameter versus Minimum Thrust for Theta Values of 2, 3, and 4